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W. D. Ervin

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ALTITUDE TEST OF THE AEROJET MODIFIED HEAVYWEIGHT FULL-SCALE CONTROLLABLE SOLID-PROPELLANT ROCKET MOTOR (CSRM-4)

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ENGINE TEST FACILITY
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AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE 37389

November 1973

Final Report for Test Conducted June 25, 1973

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APPROVAL STATEMENT

This technical report has been reviewed and is approved.

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20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Aerojet Solid Propulsion Company modified, full-scale, heavyweight, Controllable Solid Rocket Motor (CSRM-4), was successfully test fired at simulated pressure altitude in Rocket Development Test Cell J-5 of the Engine Test Facility, AEDC, on June 25, 1973. The primary test objective, propellant extinguishment, was demonstrated on five repetitive programmed firings; the five 5-sec duration firings were separated by 60-sec extinguished

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) coast periods. Motor chamber pressure at propellant extinguishment was 36, 26, 32, 30, and 26 psia for the five firings. Postfire condition of the motor was satisfactory.

PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), and was sponsored by the Advanced Ballistic Missile Defense Agency (ABMDA), U.S. Army, for the Aerojet Solid Propulsion Company (ASPC), a division of Aerojet General Corporation under Program Element 921C-1. The results of the test presented herein were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in Rocket Development Test Cell (J-5) of the Engine Test Facility on June 25, 1973, under Project No. RA207, and the manuscript was submitted for publication on September 20, 1973.

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1.0 INTRODUCTION

The ASPC Controllable Solid Rocket Motor (CSRM) is a research and development motor which is being developed to define the technology required for a variable thrust, extinguishable, multiple restart, solid-propellant rocket motor. The CSRM utilizes a high-burn-rate exponent propellant and a variable throat area nozzle to control motor chamber pressure, thereby thrust, and provide for propellant extinguishment.

Two full-scale, heavyweight CSRM's have been previously test fired by ASPC at sea-level conditions (Refs. 1 and 2). These firings indicated that the concept was feasible; however, propellant extinguishment could not be demonstrated at sea-level conditions. Two subscale (and one full-scale) CSRM's were subsequently fired under simulated pressure altitude conditions in Test Cell J-5 (Fig. 1), and the results were reported in Refs. 3, 4 and 5. Variable thrust, thrust vector control, and propellant extinguishment were achieved on the subscale firings. Variable thrust and thrust vector control were demonstrated on the firing of full-scale motor CSRM-3; however, the motor failed to achieve propellant extinguishment.

The test reported herein was for CSRM-4 which was modified based on CSRM-3 test results. Modifications included a return to the propellant formulation used successfully on the two AEDC subscale motor firings, a design alternation in the nozzle geometry, and the removal of an 18-in. cylindrical section of propellant and case from the center of the thrust chamber. Alteration of the nozzle geometry was accomplished to improve the internal aerodynamics of the nozzle system and removal of 18 in. of propellant was accomplished to reduce propellant surface area, thereby improving motor extinguishability. The primary objective of the CSRM-4 test was to demonstrate propellant extinguishment over a range of motor free volumes to provide baseline data for the CSRM system. Five identical repetitive firings were programmed in the following sequence: 400-psia chamber pressure for 3 sec, a step to 86 psia for 2 sec, extinguishment, and a 60-sec extinguished coast period.

2.0 APPARATUS

2.1 TEST ARTICLE

The ASPC modified, full-scale, heavyweight CSRM (Fig. 2) consists of a heavyweight chamber approximately 47 in. in diameter and 98 in. long, containing approximately 6000 lb of ANP-3357-4B propellant in an aft-restricted, forward finocyl, grain configuration. The propellant was fully case-bonded except in the aft boot area. The liner material is polyurethane SD-902, and the chamber insulation is filled nitrile rubber V-44 (V-45 in the aft boot only). The burn rate exponent (n) for this propellant is 0.91 in the general burn-rate expression:

$$r = aP^n$$

r = burn rate, in./sec
a = a constant (peculiar to propellant type)
P = chamber pressure, psia
n = burn-rate exponent

The ignition system for this motor is comprised of five solid-propellant igniters installed in an igniter adapter plate in the forward end of the motor.

The nozzle (Fig. 3) is equipped with a hydraulically actuated strut-mounted pintle which moves along the motor longitudinal axis to vary throat area. The pintle hydraulic actuator is located in the strut-mounted centerbody. The change in throat area as a function of pintle position for both the minimum geometric area as determined by ASPC and the effective aerodynamic area determined under cold flow test conditions at AEDC, conducted prior to the test firing of CSRM-4, is shown in Fig. 4. Movement of the pintle 8.35 in. (from the fully extended to the fully retracted position) results in a change in the geometric throat area from 114 to 319 sq in. This area change provides control of chamber pressure, thereby thrust, and propellant extinguishment.

2.2 PINTLE POSITION CONTROL SYSTEM

Position of the nozzle pintle is controlled by means of a closed-loop servocontrol system incorporating an ASPC control console and AEDC command signal generator and hydraulic supply system. The ASPC controller generates the pintle position command voltage as a function of chamber pressure feedback voltage. The AEDC command signal generator provided the time-sequenced reference voltages to the ASPC controller; AEDC interconnects were provided to complete this control loop. The pintle is held in the ignition position by using a potentiometer to supply a reference voltage to the servocontrol loop. After ignition, transfer to chamber pressure feedback voltage control is made, and the potentiometer reference is replaced by a computer reference voltage corresponding to the target chamber pressure feedback voltage. The pintle is retracted to the maximum geometric throat area position for extinguishment (319 sq in.). An ASPC analog computer was utilized to simulate chamber pressure feedback voltage for functional actuation checks of the pintle control system. The hydraulic system was capable of operating at a 4500-psia pressure level and providing an instantaneous fluid flow rate of 60 gpm with 1000-psi differential across the servo valve.

2.3 TEST CELL AND INSTALLATION

Rocket Development Test Cell (J-5) (Fig. 1 and Ref. 6) is a test complex for testing solid-propellant rocket motors with thrust levels nominally up to 125,000 lbf at simulated altitudes of approximately 100,000 ft. A steam ejector-diffuser system was used in conjunction with rotating exhaust machinery to provide altitude simulation during the firings and coast periods.

2.4 INSTRUMENTATION

Table 1 presents a summary of motor instrumentation. Instrumentation calibration techniques are described in Appendix A. Uncertainties of the J-5 instrument systems are presented in Table 2. The method of calculation of these uncertainties is presented in Ref. 7.

The types of data acquisition and recording systems used during this test were a multiple-input digital data acquisiton system scanning each parameter at a basic rate of 200 samples/sec (selected parameters supercommutated to 1000 samples/sec) and recording on magnetic tape; single-input continuous recording analog system recording in pulse form on magnetic tape; frequency modulation (FM) analog systems recording on magnetic tape; and galvanometer-type oscillographs recording at paper speeds of 16 in./sec. Motion-picture cameras provided a permanent visual recording of the firing. All digital data reduction was accomplished with an IBM 370 computer.

3.0 MOTOR CHRONOLOGY AND PROCEDURES

The motor chamber was received at AEDC on May 7, 1973, and was unloaded at the radiographic laboratory. The nozzle assembly was received on June 13, 1973. The conditioning temperature and humidity to which the motor was exposed while at AEDC are summarized in Table 3. An as-received inspection of the motor, nozzle assembly, and other components was performed. No defects or damage during shipment were noted.

Radiographic inspection of the motor was completed on May 18. No propellant voids or separations were noted. A summary of the inspection results was transmitted to ASPC. The original radiographic films are on file at AEDC.

The motor was moved to the Rocket Preparation Area on June 14, and the nozzle assembly was installed on the motor on June 15. Instrumentation (Table 1) was installed in accordance with the ASPC Test Plan (Ref. 8). After installation of the chamber and igniter pressure transducers, the motor was pressure checked in accordance with test procedures supplied by ASPC. The leak rate was within limits specified by ASPC. Test stand adapting equipment was then installed on the motor. Prefire nozzle exit plane measurements were made at 30-deg intervals referenced to 0-deg target down. These measurements are presented in Table 4 along with prefire nozzle throat annular gap measurements taken with the nozzle pintle in the fully extended position. The motor was transported to the test cell, installed, and aligned in the test cell on June 19.

ASPC then electrically balanced, trimmed, and functionally tested the electronic systems for nozzle pintle control. Physical calibration of the nozzle pintle control system in preparation for the test firing was conducted.

Sequence checks for the test were performed on June 22 and June 25. The sequence run checks the operation of the test article and facility systems which support the test. After completion of the sequence checks, the motor igniter squibs were installed, final preparation of facility support systems for the test was performed, and a final test cell inspection was accomplished.

The test cell was evacuated to altitude conditions at 2030 hours on June 25, and instrumentation recorder calibrations were performed. Test cell pressure during calibrations was 0.40 psia. The test firing was accomplished at 2205 hours on June 25. Test results are presented in Section 4.0 of this report. The motor was removed from the test cell on June 26 and transported to the Rocket Preparation Area. Postfire nozzle exit plane measurements were made and recorded in Table 4. The motor was disassembled for inspection on June 27, reassembled, and shipped to ASPC on July 30, 1973.

The methods used to calculate the ballistic parameters presented in this report are presented in Appendix B.

4.0 RESULTS AND DISCUSSION

4.1 GENERAL

The primary test objective of the Aerojet modified, full-scale, heavyweight CSRM-4 test was to demonstrate propellant extinguishment over a range of motor free volumes to provide baseline design data for the Controllable Solid Rocket Motor system.

Five motor firings were programmed, each to consist of a 3-sec burn at 400 psia and a 2-sec burn at 86 psia followed by propellant extinguishment and a 60-sec coast period was scheduled between firings. A summary of motor performance for this test is presented in Table 5.

The ASPC pintle control system experienced "hunting" on the high-pressure step during the first three firings. This resulted in oscillations in pintle position, and thus in chamber pressure and thrust during these firings. These oscillations did not occur on the fourth and fifth firings; however, erosion of the pintle had progressed to the point that the pintle was fully extended against the mechanical stop for the high-pressure step on these two firings.

The ASPC control console has been used throughout the CSRM program and has been observed to be less than adequate for stable control of motor thrust. Inability to maintain a steady-state thrust level and pintle "hunting" have been characteristic of the control system throughout the program as well as on the firing reported herein.

Since propellant extinguishment was the objective of the CSRM-4 test and development of a completely adequate and qualified control system is beyond the scope of this test program, the attainment of steady thrust levels was considered to be of secondary importance in the analysis of CSRM-4 test results.

The higher chamber pressure and thrust levels on the fifth firing as compared with these levels on the fourth firing with the pintle fully extended in both cases is attributed to a greater available propellant burn surface area for the fifth firing.

4.2 FIRST TEST FIRING

The motor was ignited successfully for the first test firing at 88,000-ft (geometric pressure altitude, Z, Ref. 9) simulated pressure altitude. During motor ignition, the nozzle pintle was held in the 88-percent-of-full-extension position which corresponds to a nozzle geometric throat area of 125 sq in. A history of igniter pressure during the ignition transient is presented in Fig. 5. Mode transfer from pintle ignition position control to chamber pressure feedback control of the pintle occurred at T + 0.160. Chamber pressure and thrust at the time of mode transfer were 378 psia and 83,800 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 6. Nozzle pintle command voltage and pintle position are presented in Fig. 7. Chamber pressure averaged 335 psia during the high-pressure step and 147 psia during the low-pressure step. The extinguishment command was given at T + 5.175 sec at 183-psia chamber pressure, and extinguishment occurred at T + 5.78 sec at 36 psia. Chamber pressure during extinguishment is presented in Fig. 8.

4.3 SECOND TEST FIRING

The motor was successfully ignited for the second test firing at T + 65.145 sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held in the fully extended position which corresponds to a nozzle geometric throat area of 113 sq in. A history of igniter pressure during the ignition transient is presented in Fig. 9. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at T + 65.275 sec. Chamber pressure and thrust at the time of mode transfer were 430 psia and 81,000 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 10. Nozzle pintle command voltage and pintle position are presented in Fig. 11. Chamber pressure averaged 402 psia during the high-pressure step and 147 psia during the low-pressure step. The extinguishment command was given at T + 70.285 sec at 189-psia chamber pressure, and extinguishment occurred at T + 70.86 sec at 26 psia. Chamber pressure during extinguishment is presented in Fig. 12.

4.4 THIRD TEST FIRING

The motor was successfully ignited for the third test firing at T + 130.245 sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held in the fully extended position. A history of igniter pressure during the ignition transient is presented in Fig. 13. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at T + 130.385 sec. Chamber pressure and thrust at the time of mode transfer were 316 psia and 62,400 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 14. Nozzle pintle command voltage and pintle position are presented in Fig. 15. Chamber pressure averaged 274 psia during the high-pressure step and 136 psia during the low-pressure step. The extinguishment command was given at T + 135.425 sec at 135-psia chamber pressure, and extinguishment occurred at T + 135.85 sec at 32 psia. Chamber pressure during extinguishment is presented in Fig. 16.

4.5 FOURTH TEST FIRING

The motor was successfully ignited for the fourth test firing at T + 195.360 sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held in the fully extended position. A history of igniter pressure during the ignition transient is presented in Fig. 17. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at T + 195.505 sec. Chamber pressure and thrust at the time of mode transfer were 238 psia and 44,900 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 18. Nozzle pintle command voltage and pintle position are presented in Fig. 19. Chamber pressure averaged 224 psia during the high-pressure step and 127 psia during the low-pressure step. The extinguishment command was given at T + 200.520 sec at 151-psia chamber pressure, and extinguishment occurred at T + 201.05 sec at 30 psia. Chamber pressure during extinguishment is presented in Fig. 20.

4.6 FIFTH TEST FIRING

The motor was successfully ignited for the fifth test firing at T + 260.480 sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held in the fully extended position. A history of igniter pressure during the ignition transient is presented in Fig. 21. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at T + 260.625 sec. Chamber pressure and thrust at the time of mode transfer were 216 psia and 40,000 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 22. Nozzle pintle command voltage and pintle position are presented in Fig. 23. Chamber pressure averaged 277 psia during the high-pressure step and 127 psia during the low-pressure step. The extinguishment command was given at 265.645 sec at 120-psia chamber pressure, and extinguishment occurred at 266.12 sec at 26 psia. Chamber pressure during extinguishment is presented in Fig. 24.

4.7 STRUCTURAL INTEGRITY

Postfire condition of the motor (Fig. 25) was visually determined to be satisfactory. There were no structural anomalies noted during postfire disassembly and inspection (Fig. 26) of the motor at AEDC.

5.0 SUMMARY OF RESULTS

ASPC modified, full-scale, heavyweight CSRM-4 was tested at simulated pressure altitude in Rocket Development Test Cell J-5 at AEDC on June 25, 1973. The primary objective of the test was to demonstrate propellant extinguishment at the conclusion of each of five identical programmed firings. The results of the test are summarized as follows:

1. Motor propellant extinguishment was demonstrated when commanded from chamber pressure levels of 183, 189, 135, 151, and 120 psia on the first through the fifth firings, respectively. The chamber pressure levels at propellant extinguishment on the five firings were 36, 26, 32, 30, and 26 psia, respectively.

2. Motor postfire condition was satisfactory.

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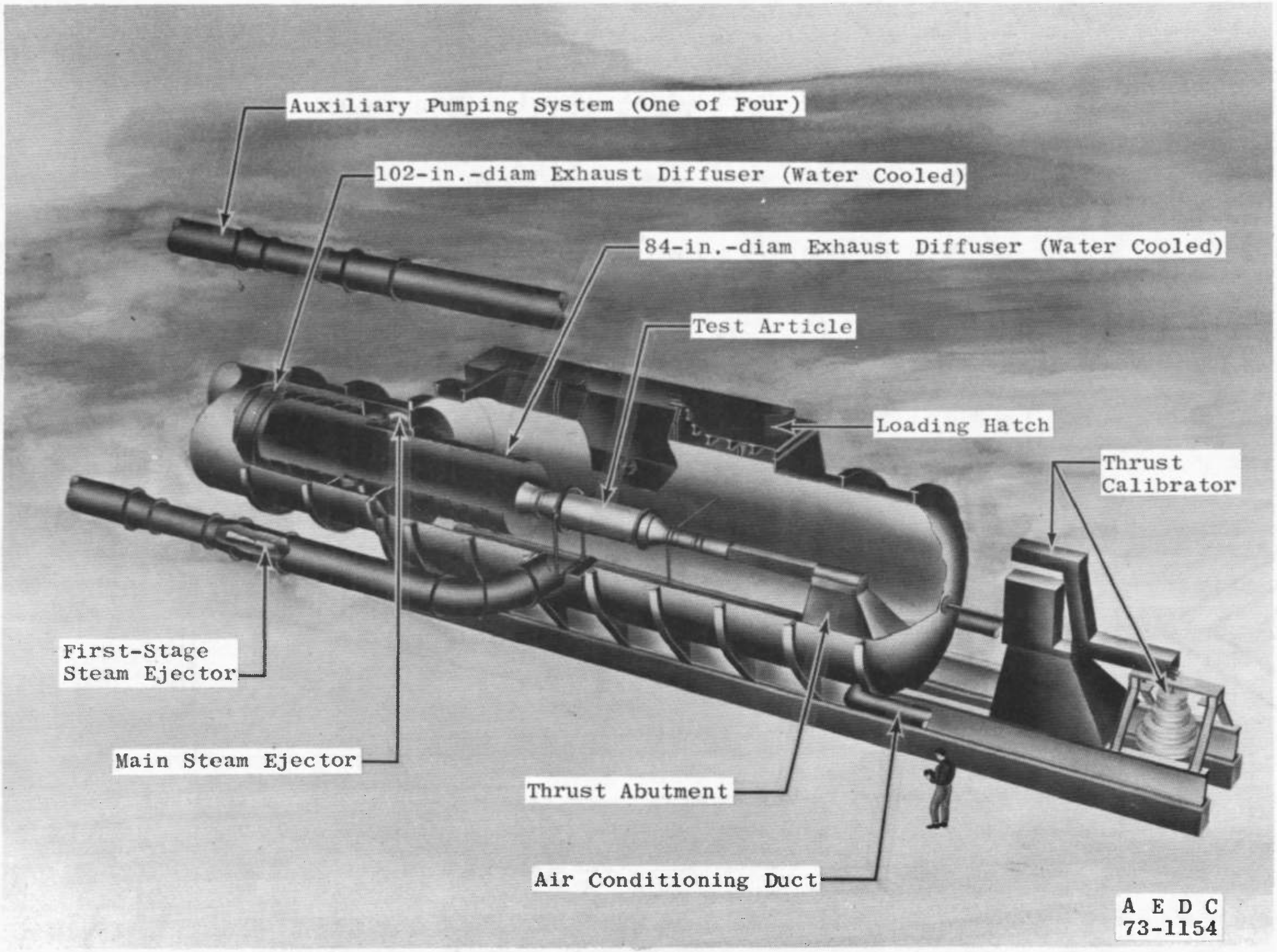
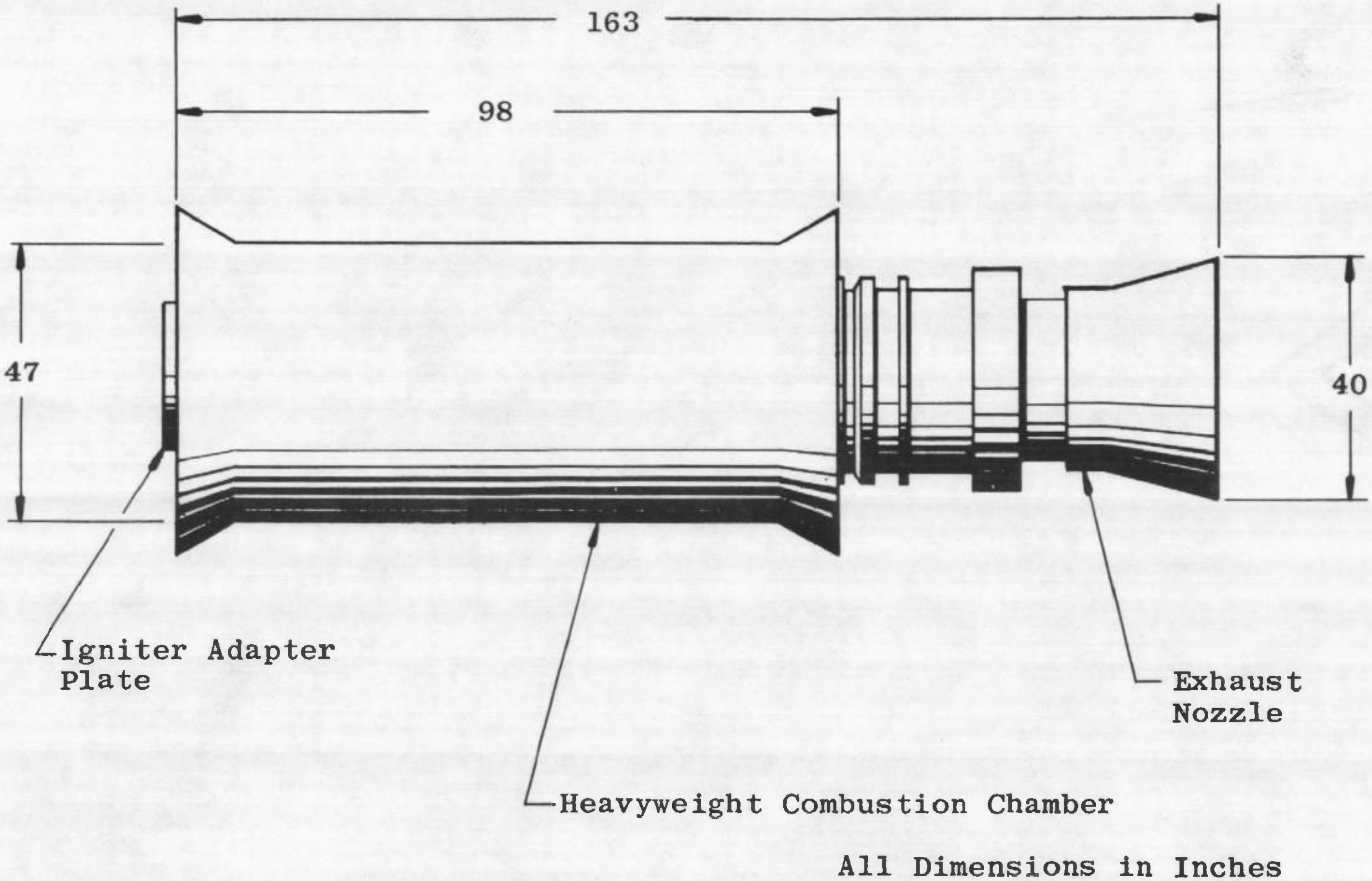
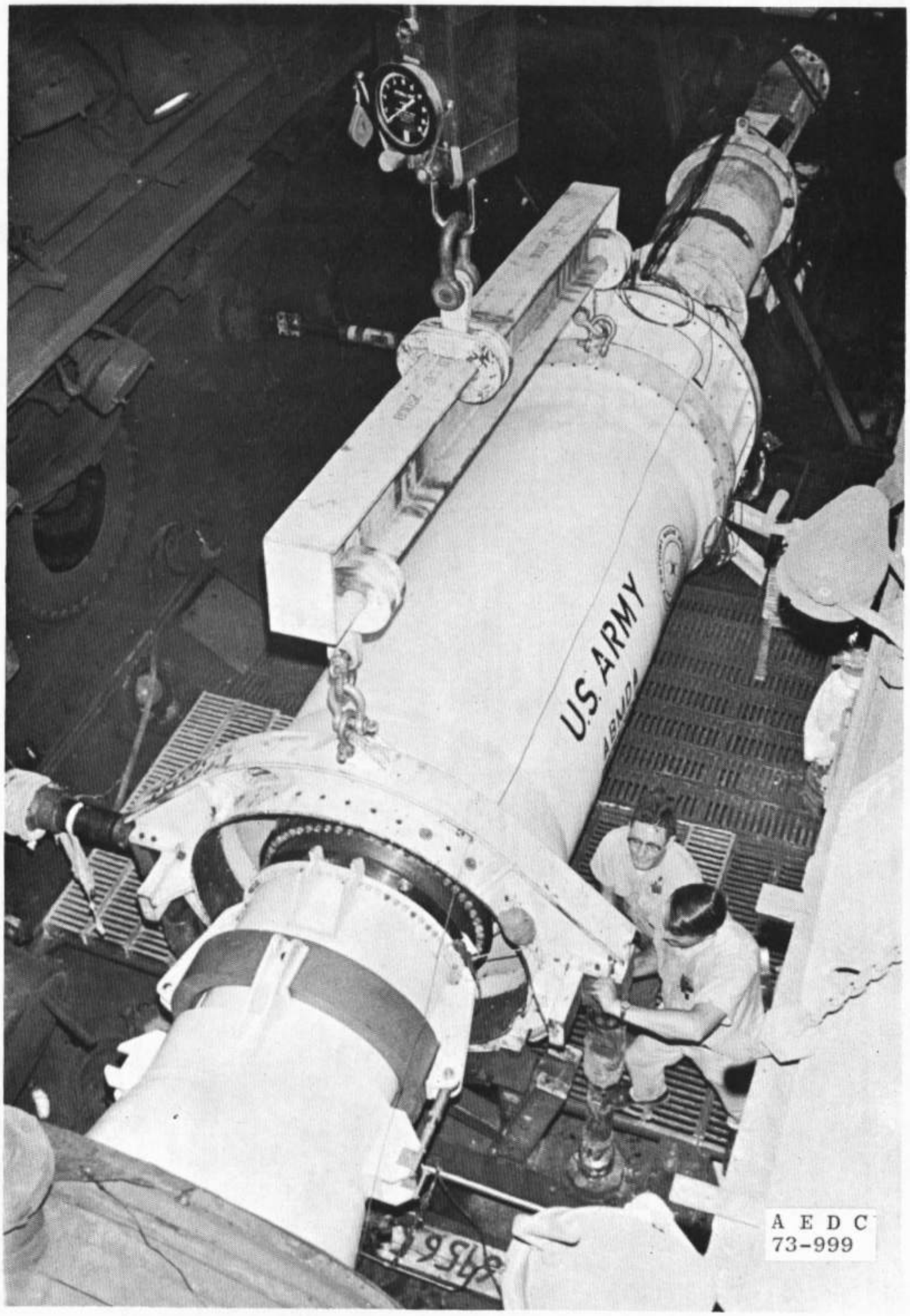


Figure 1. Rocket development test cell J-5.



a. Schematic

Figure 2. ASPC modified, full-scale, heavyweight, controllable solid rocket motor.



b. Motor installation in J-5 test cell.
Figure 2. Concluded.

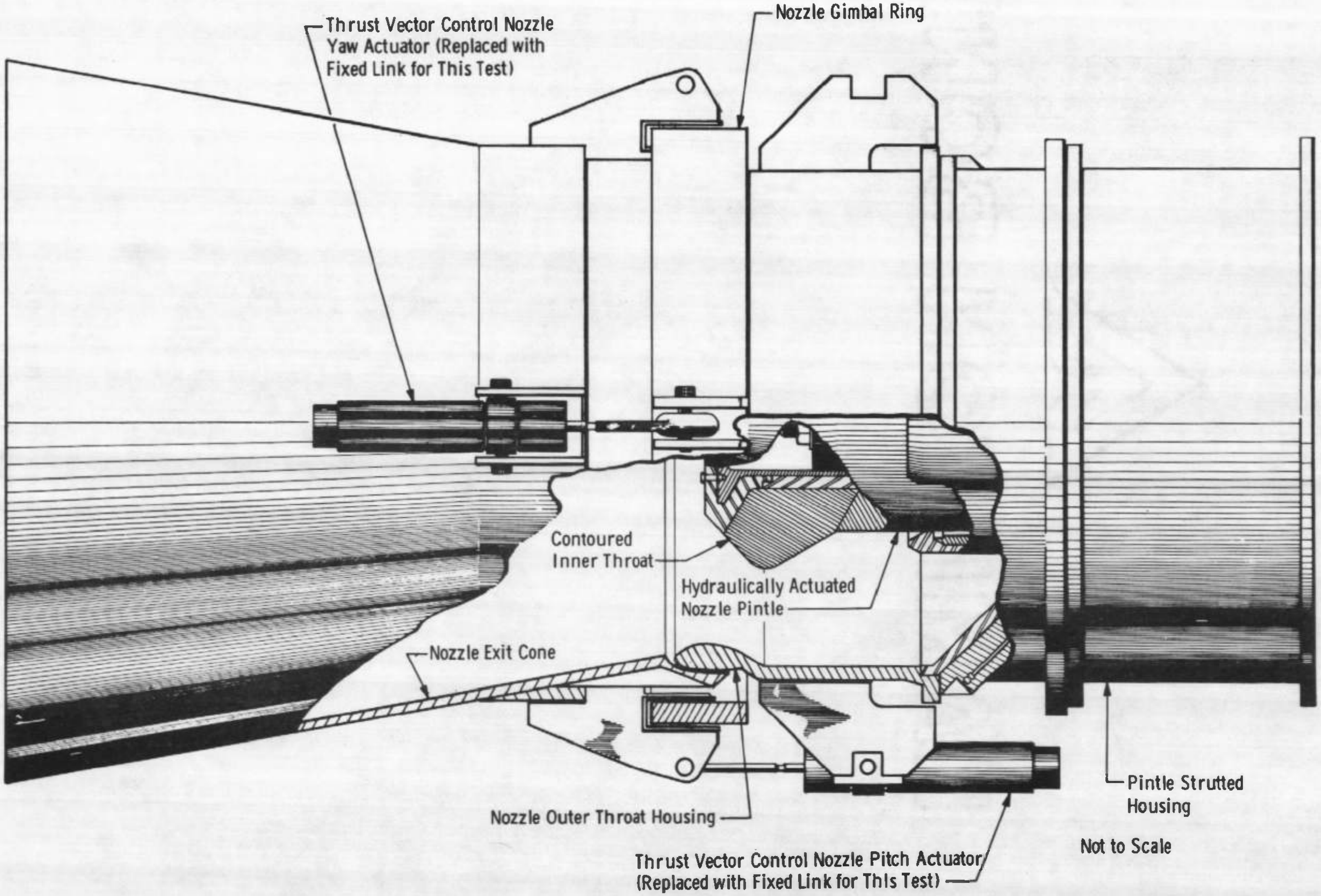


Figure 3. Nozzle assembly.

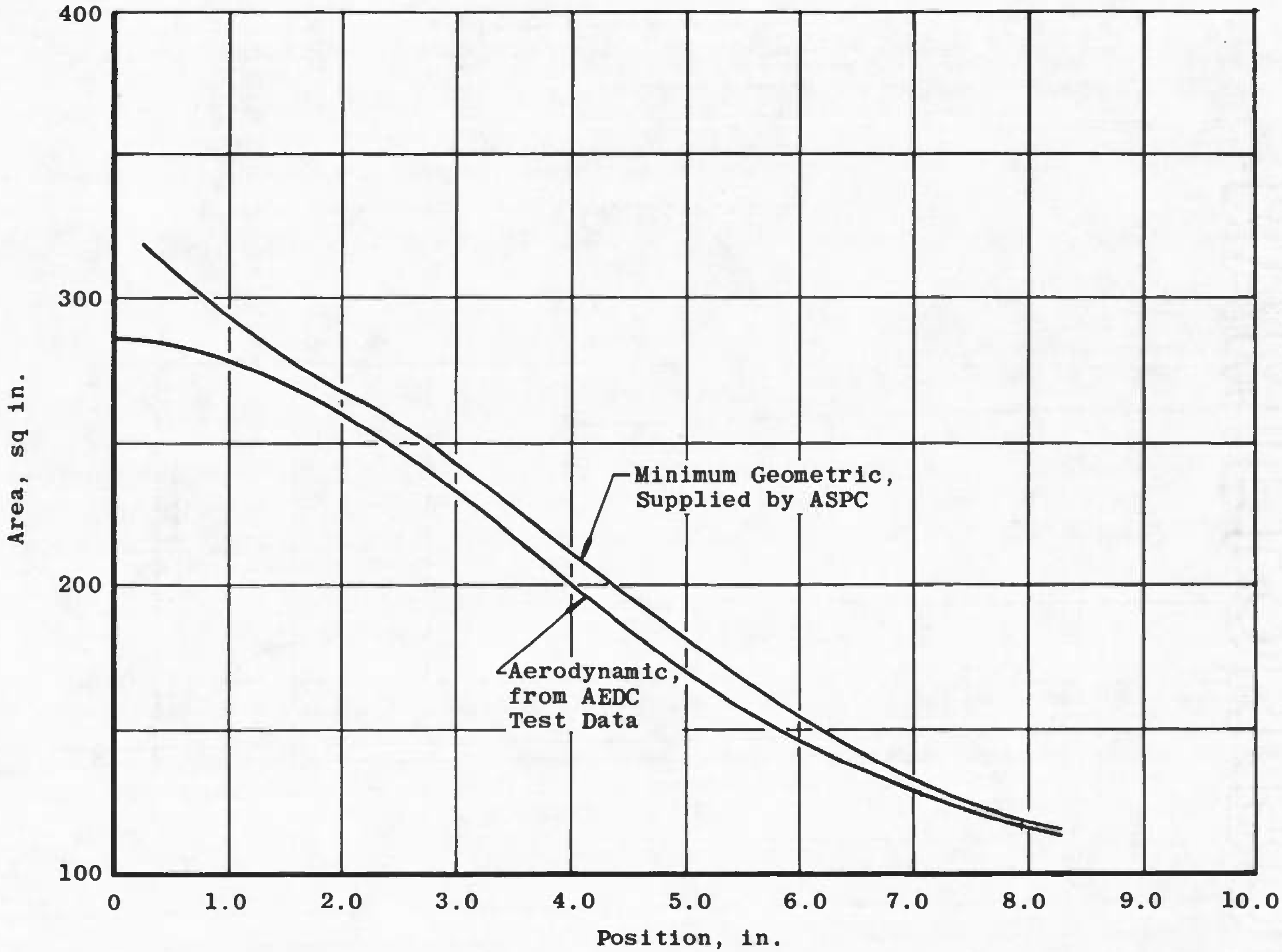


Figure 4. Nozzle throat area versus pintle position.

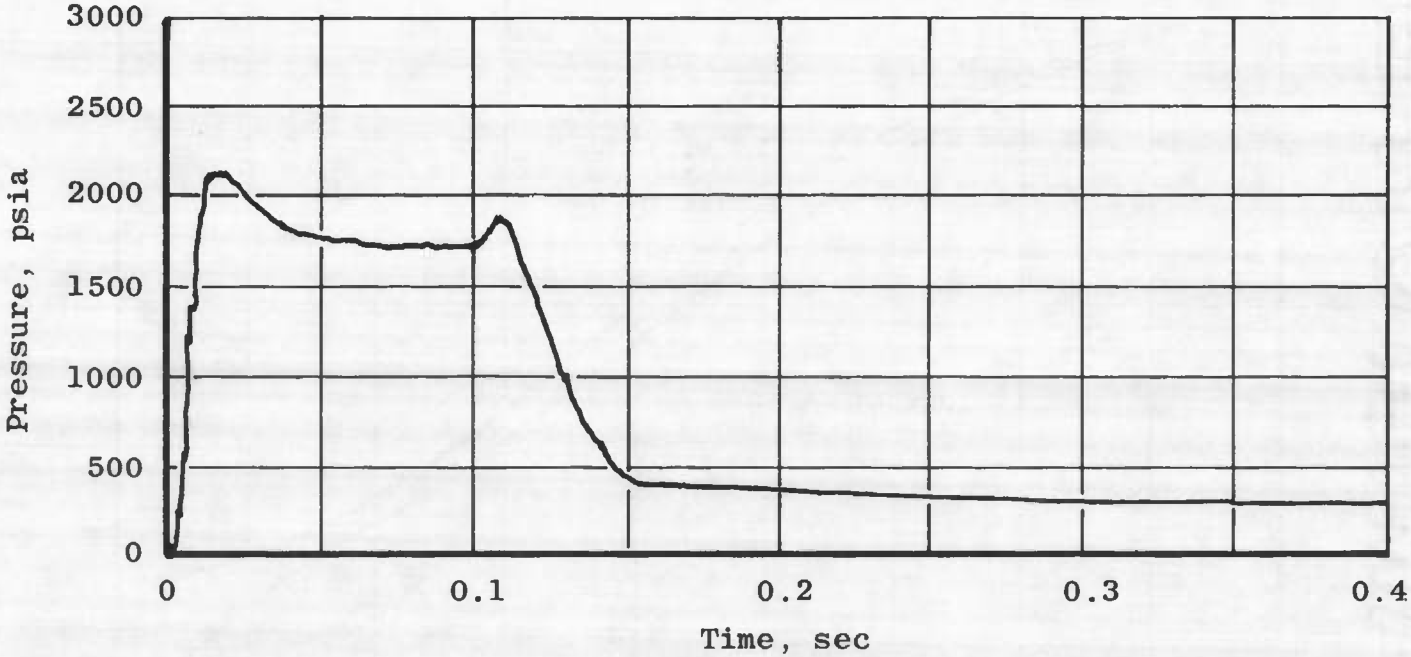


Figure 5. Igniter pressure during ignition transient, first firing.

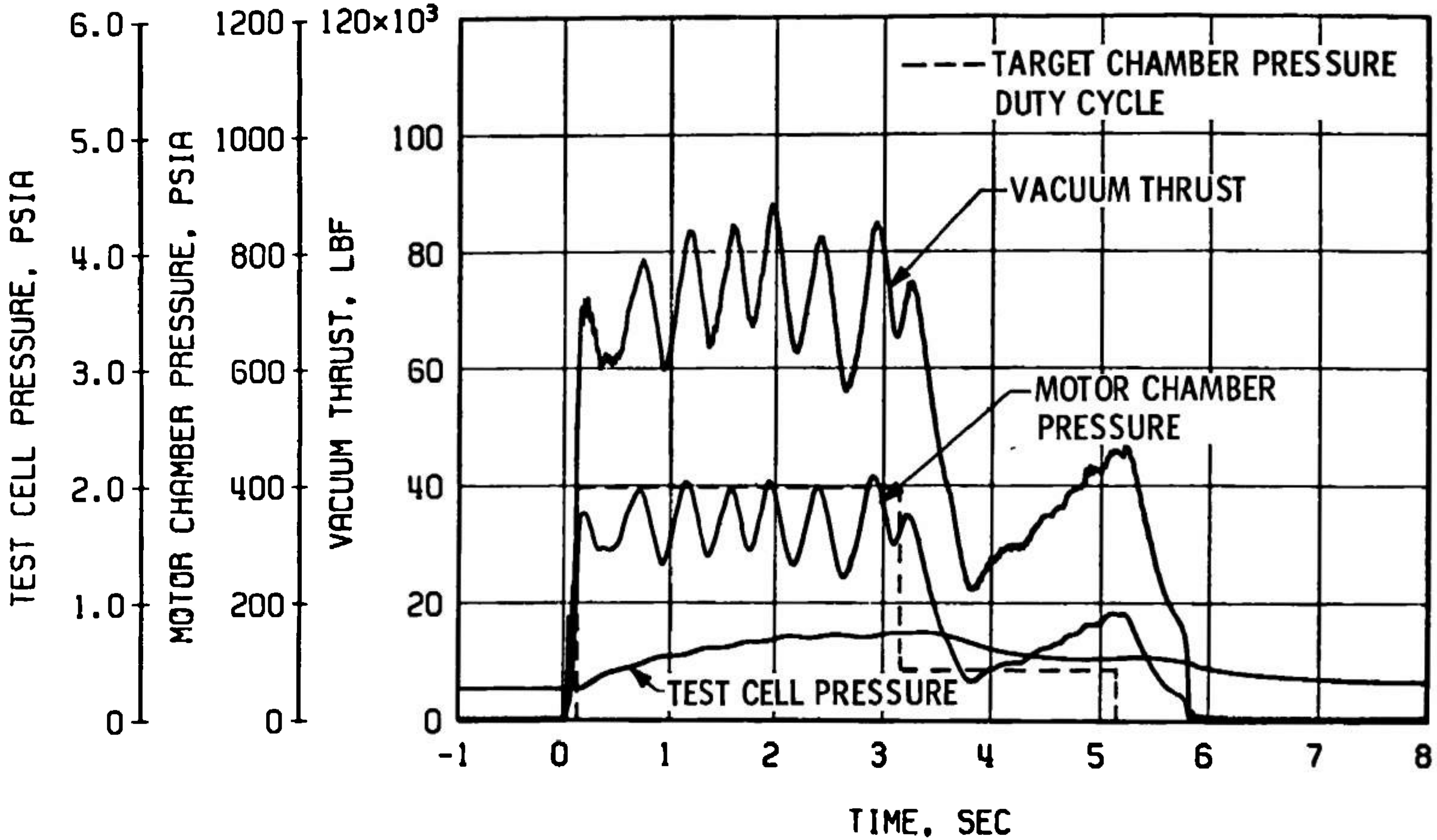
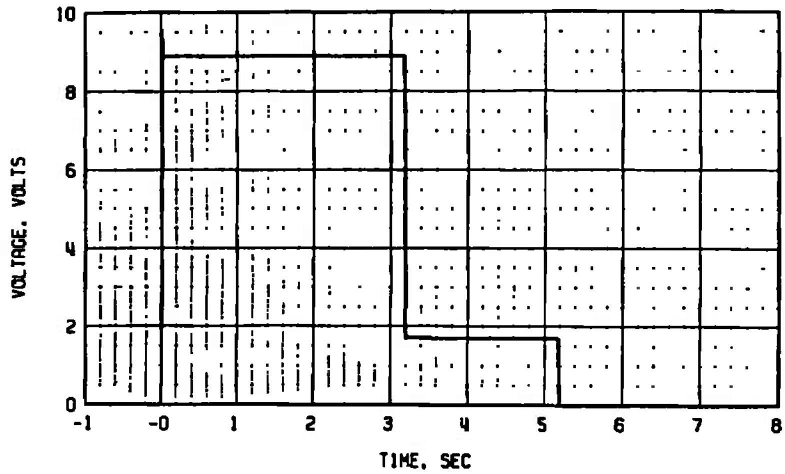
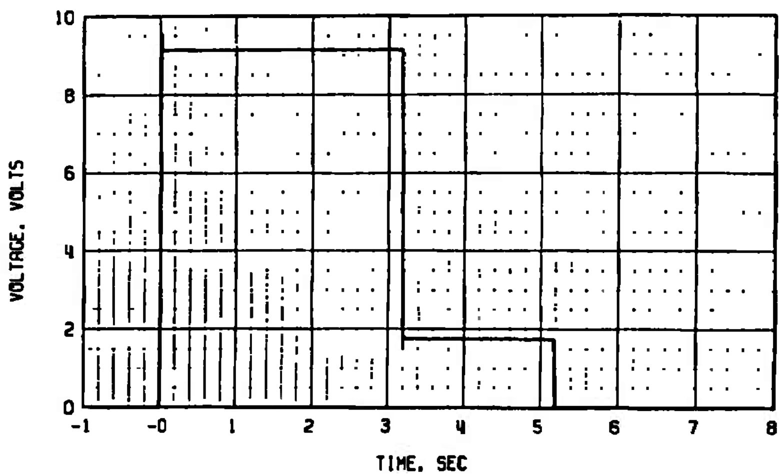


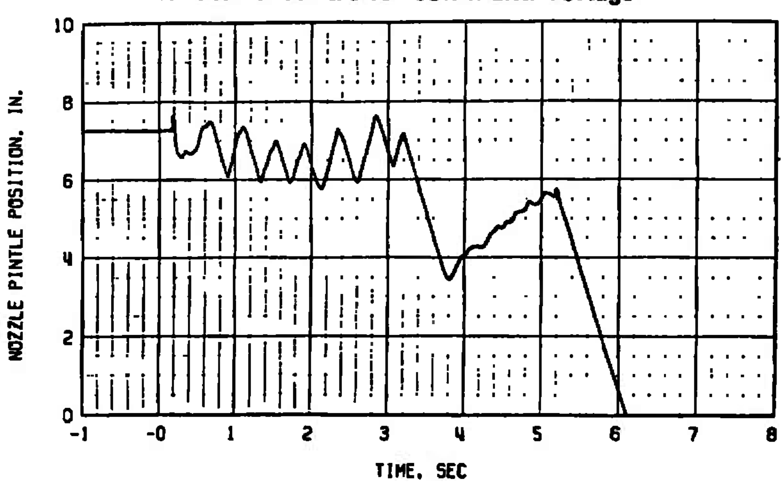
Figure 6. Vacuum axial thrust, chamber pressure, and test cell pressure, first firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 7. Nozzle pintle command voltage and position, first firing.

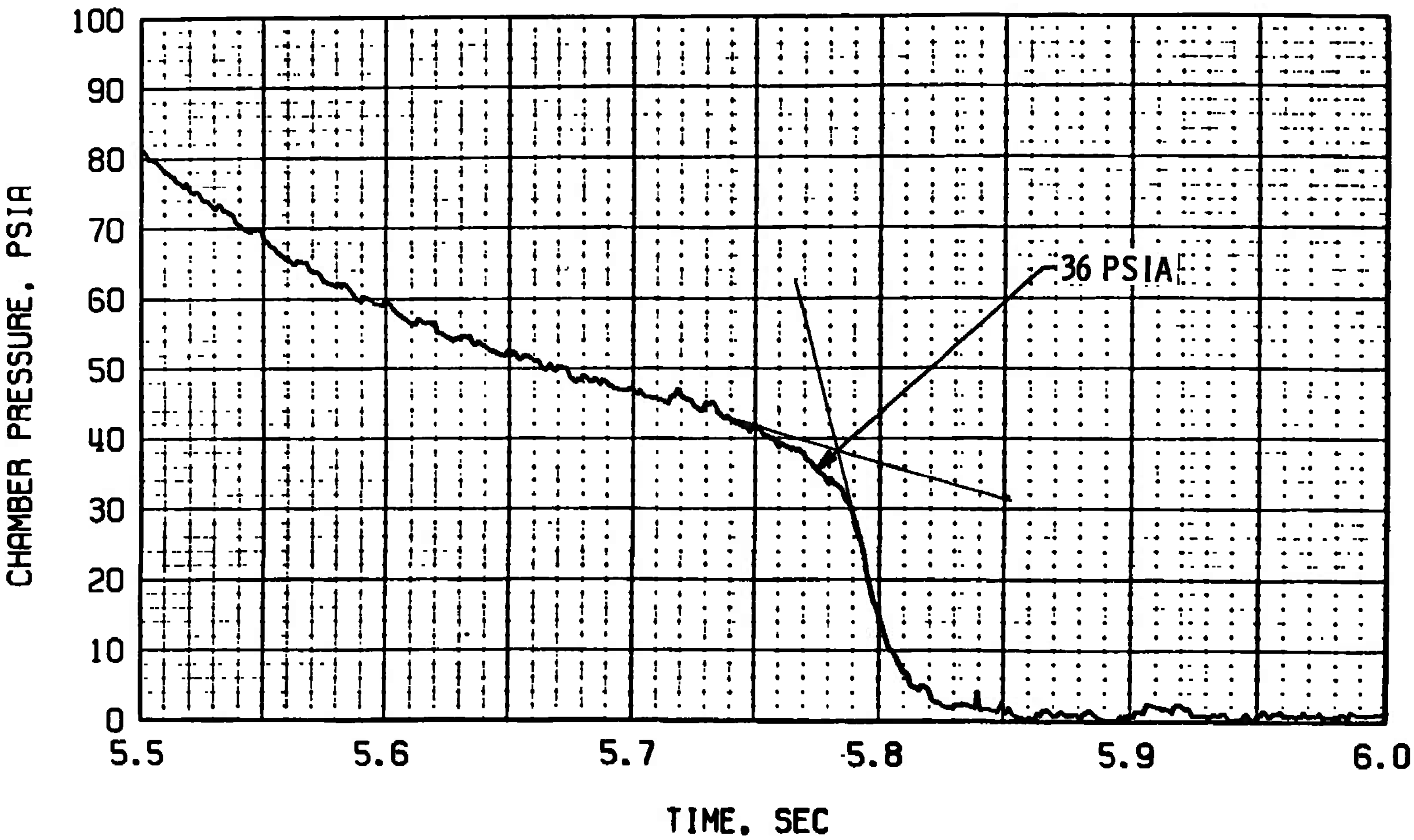


Figure 8. Chamber pressure during extinguishment, first firing.

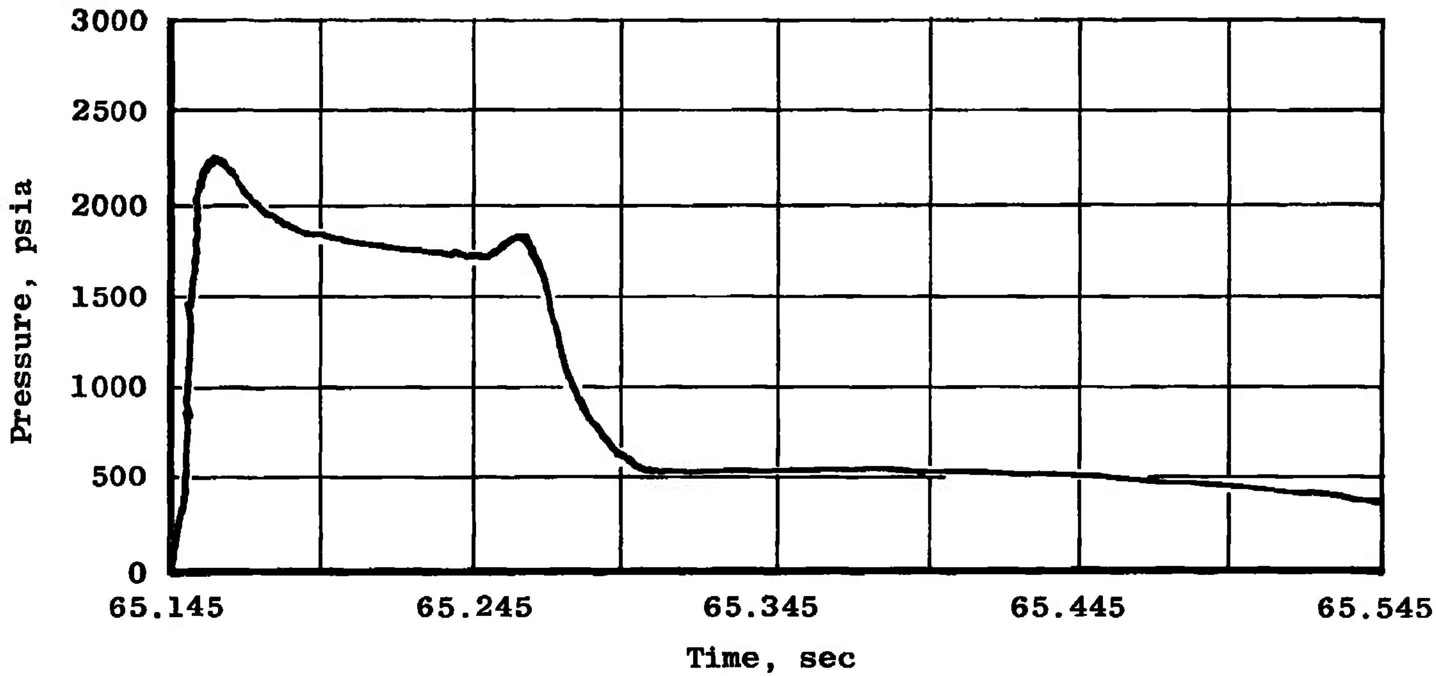


Figure 9. Igniter pressure during ignition transient, second firing.

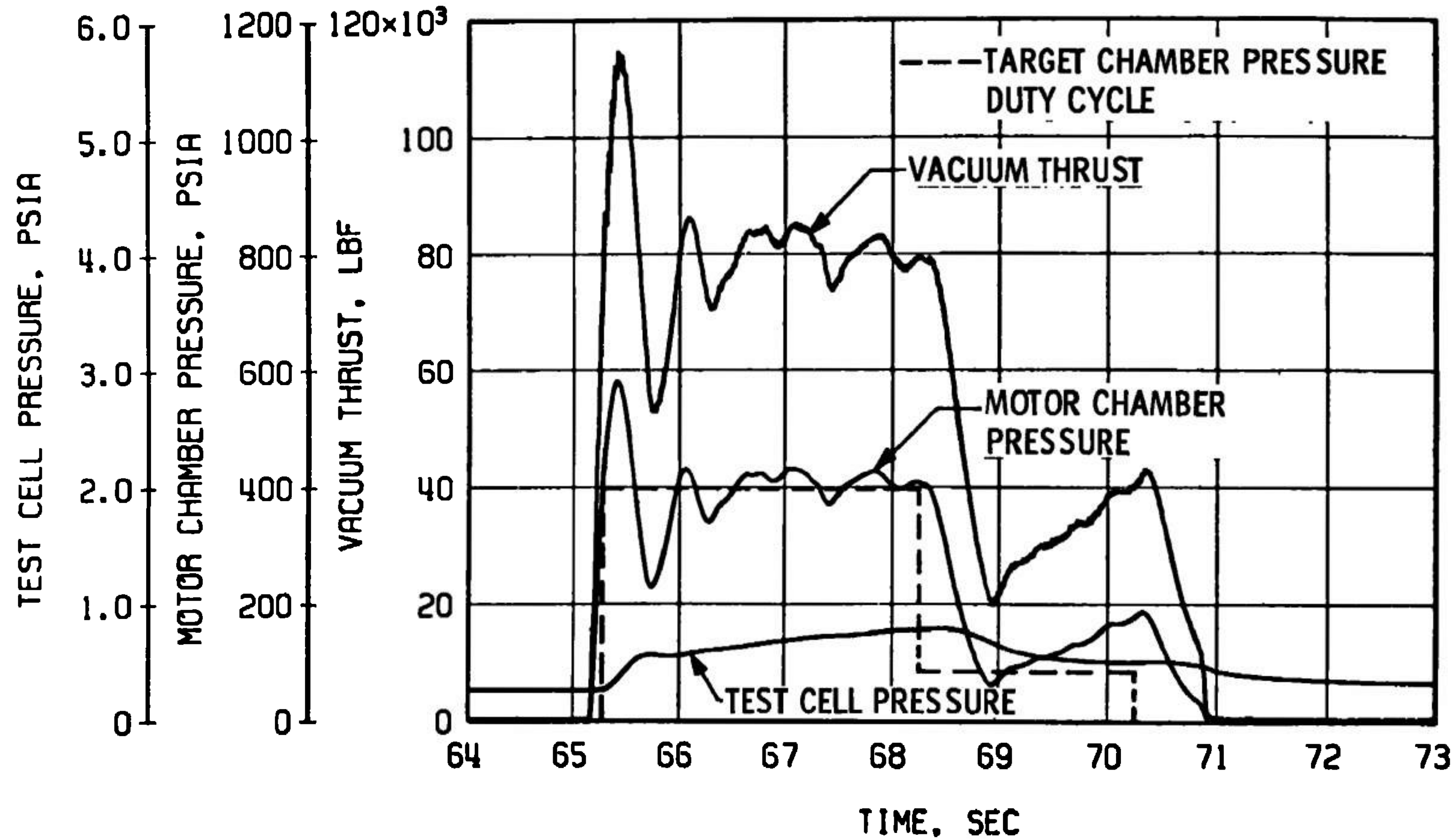
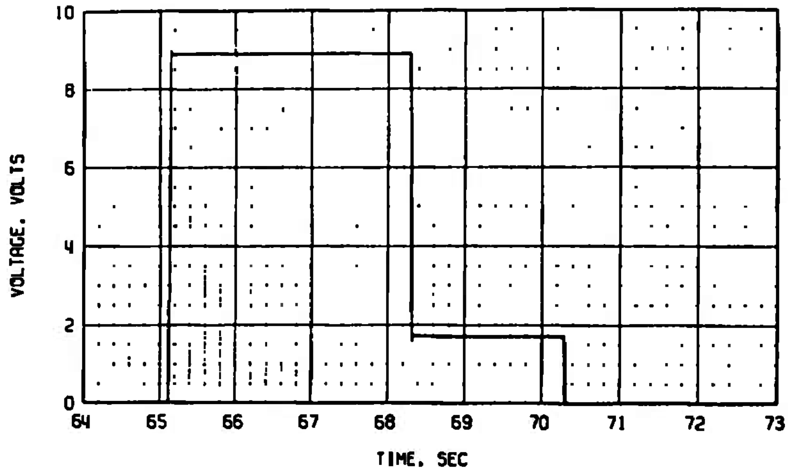
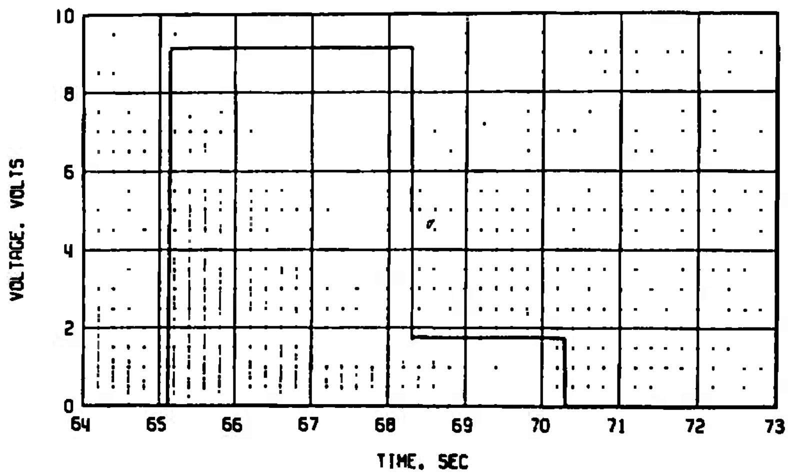


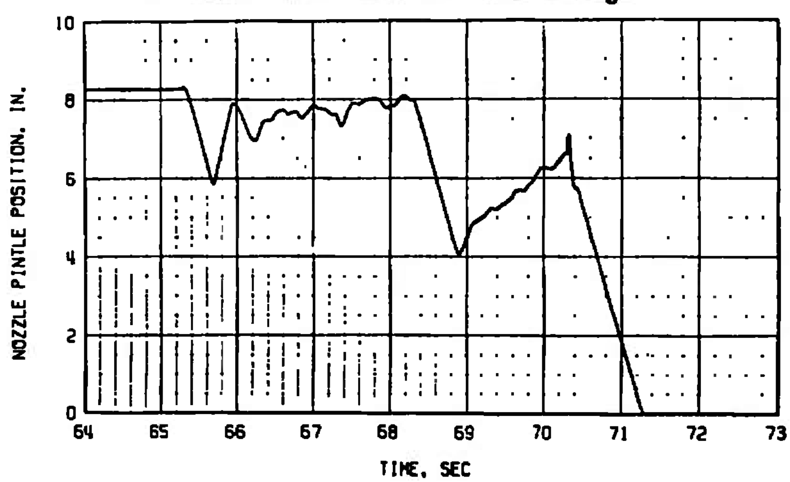
Figure 10. Vacuum axial thrust, chamber pressure, and test cell pressure, second firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 11. Nozzle pintle command voltage and position, second firing.

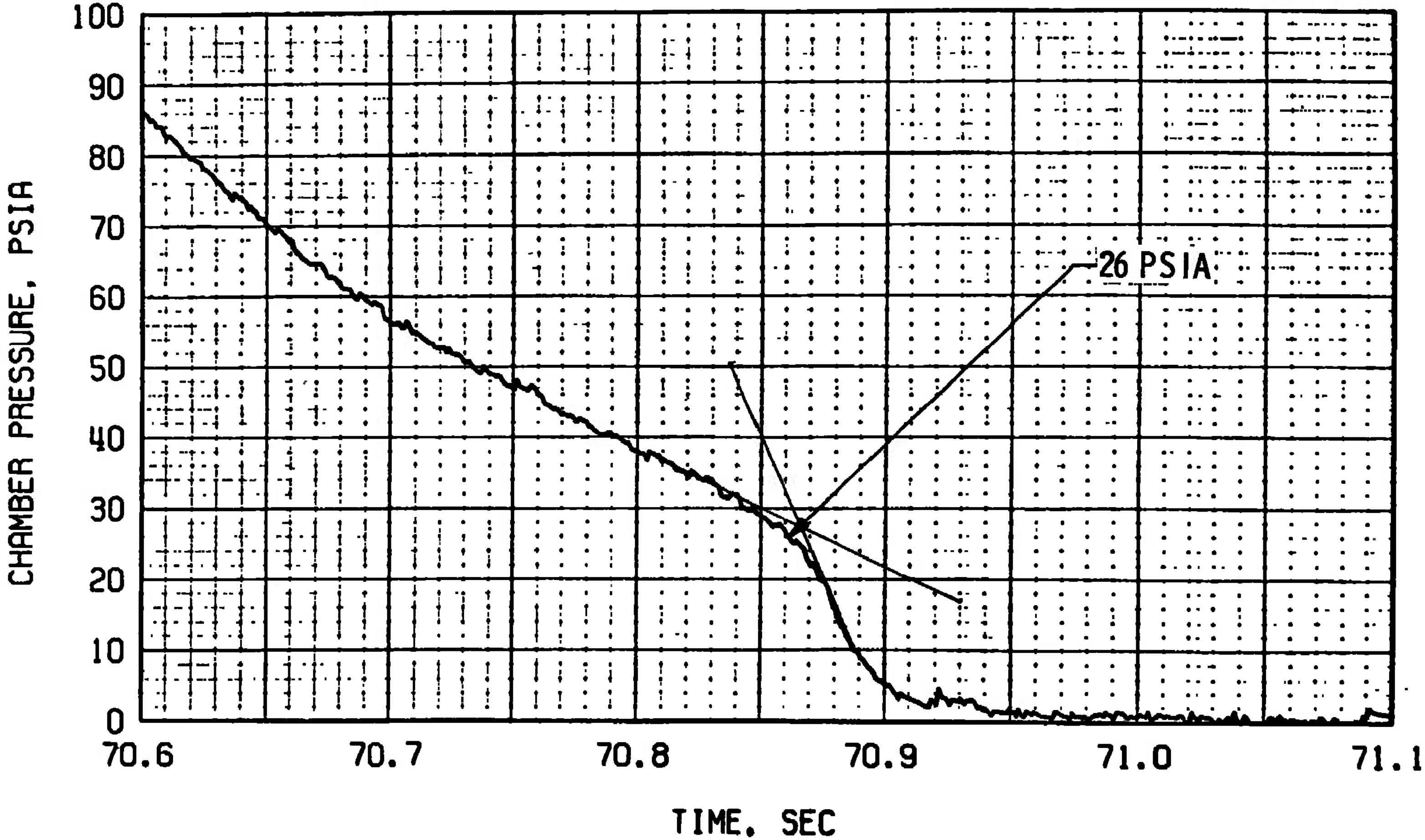


Figure 12. Chamber pressure during extinguishment, second firing.

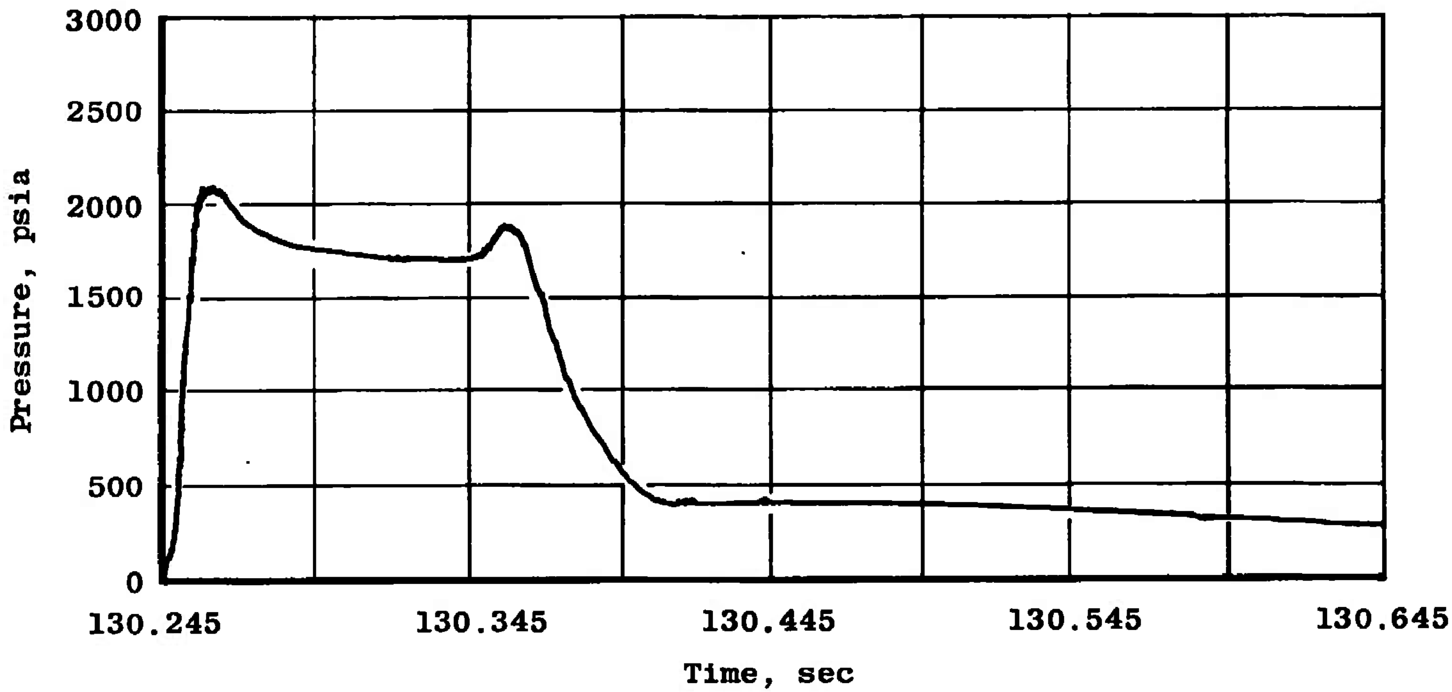


Figure 13. Igniter pressure during ignition transient, third firing.

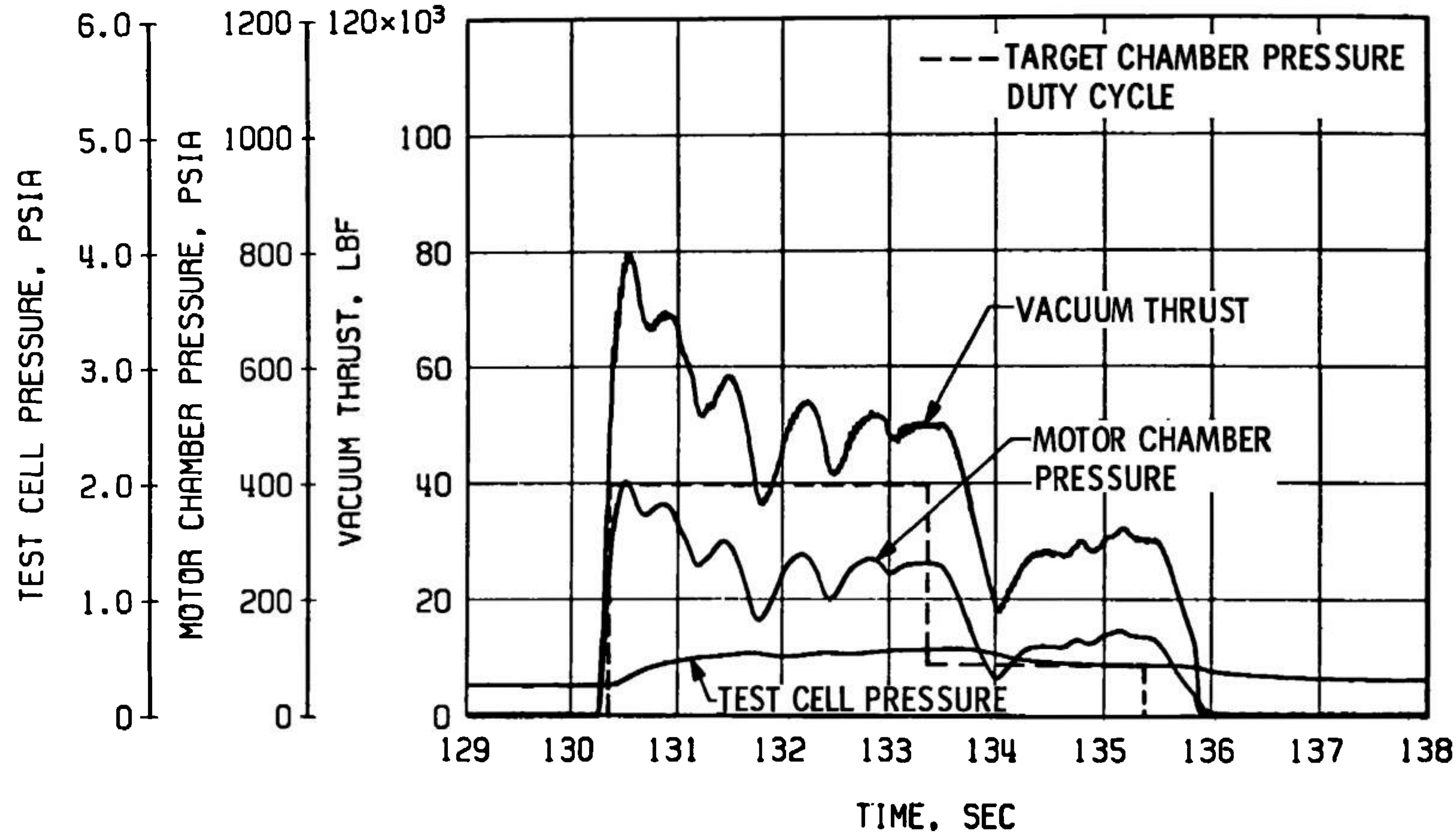
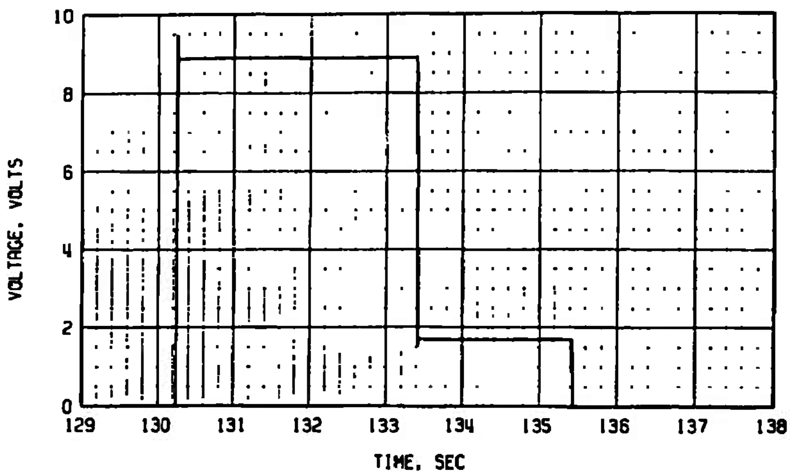
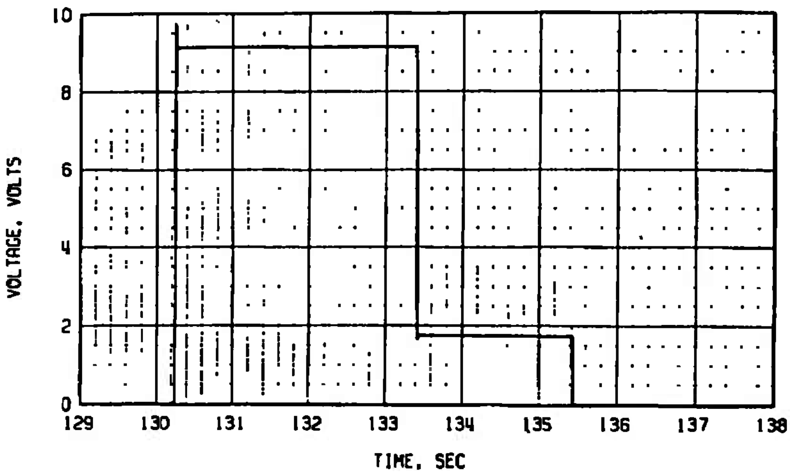


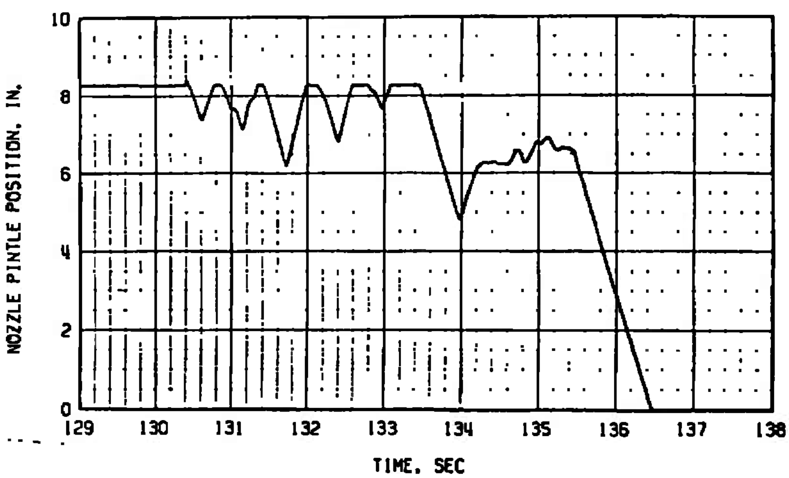
Figure 14. Vacuum axial thrust, chamber pressure, and test cell pressure, third firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 15. Nozzle pintle command voltage and position, third firing.

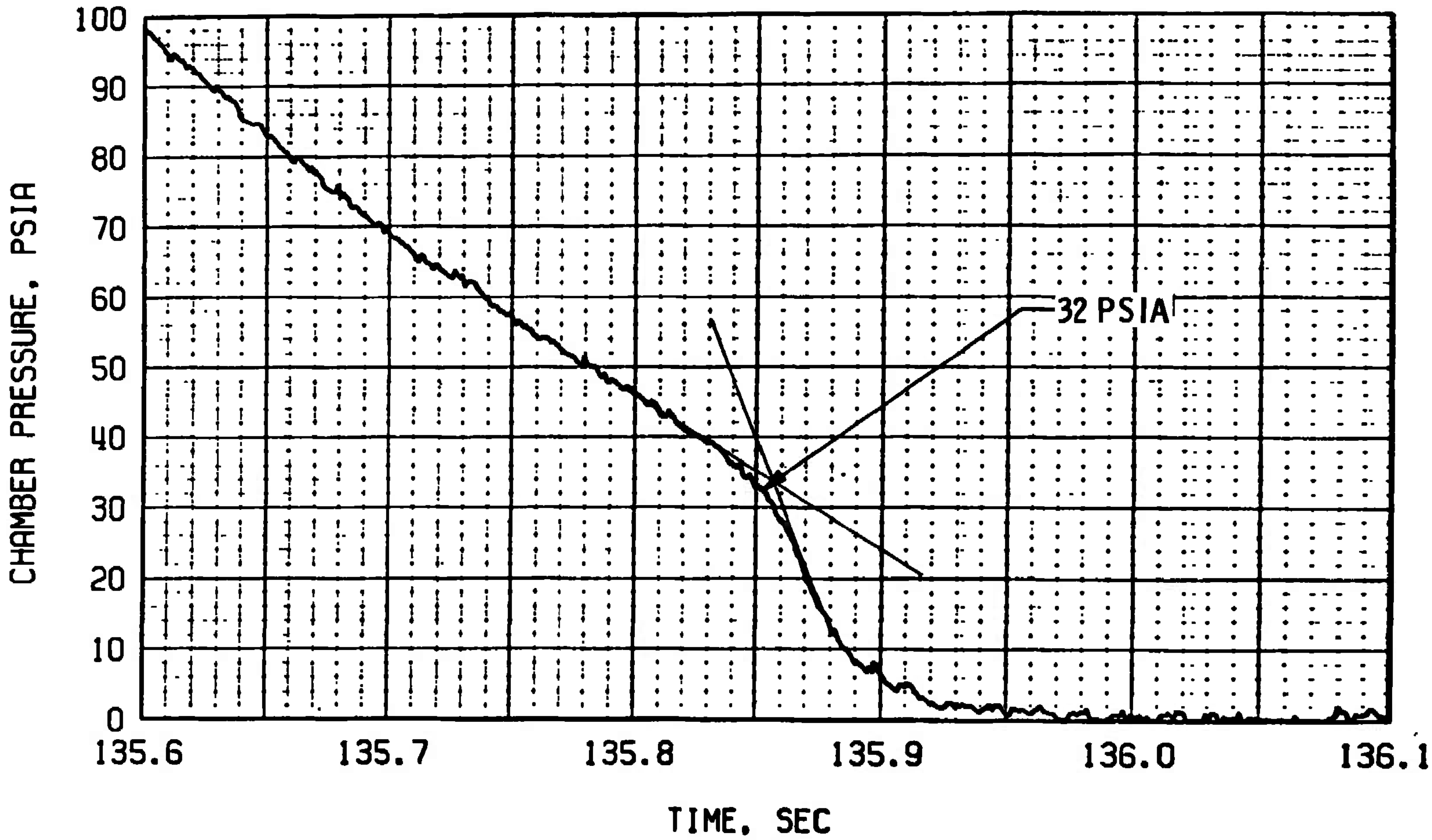


Figure 16. Chamber pressure during extinguishment, third firing.

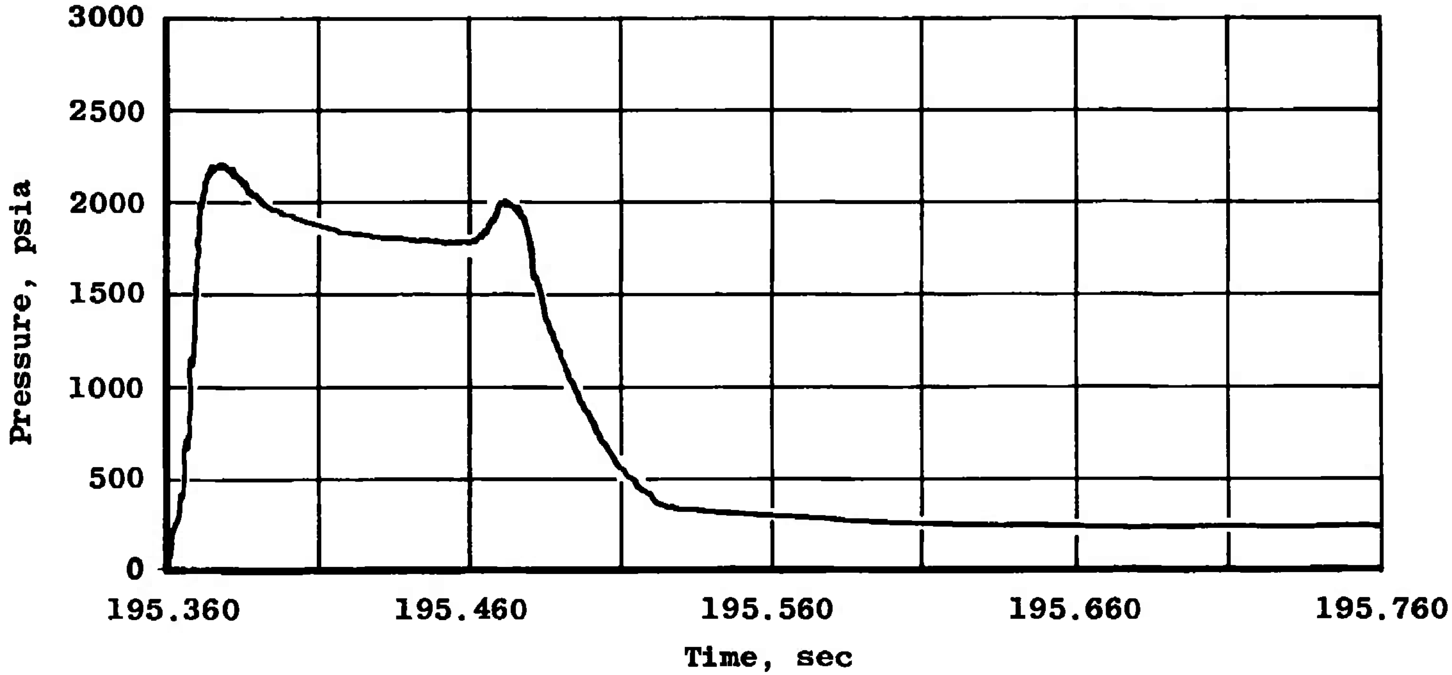


Figure 17. Igniter pressure during ignition transient, fourth firing.

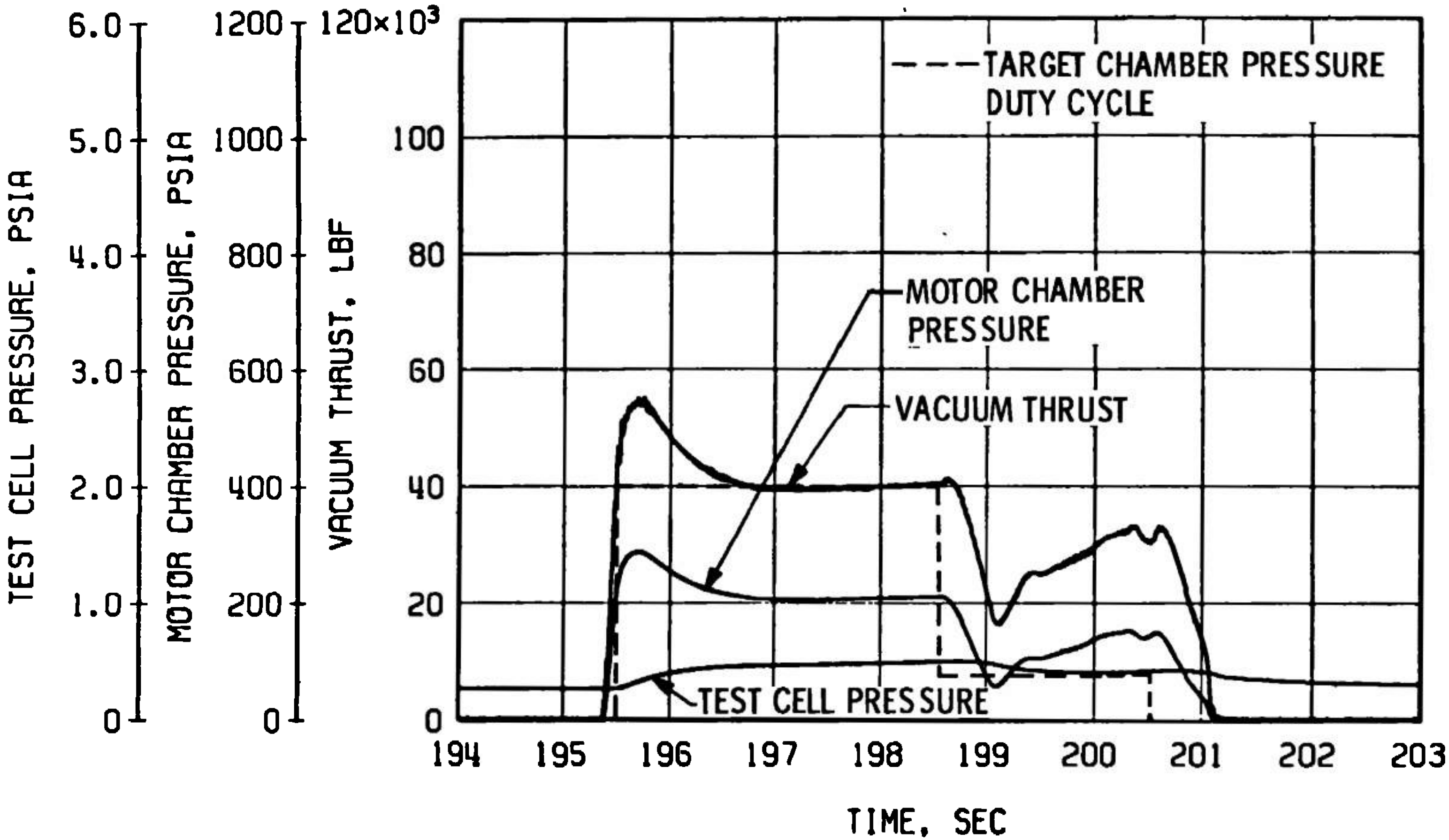
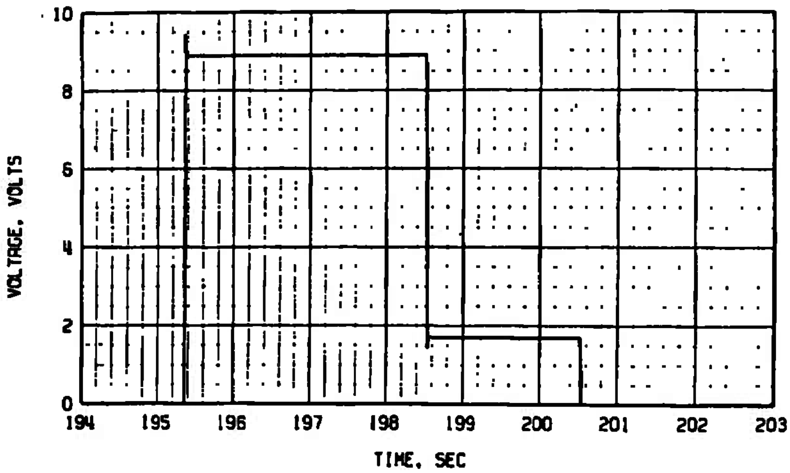
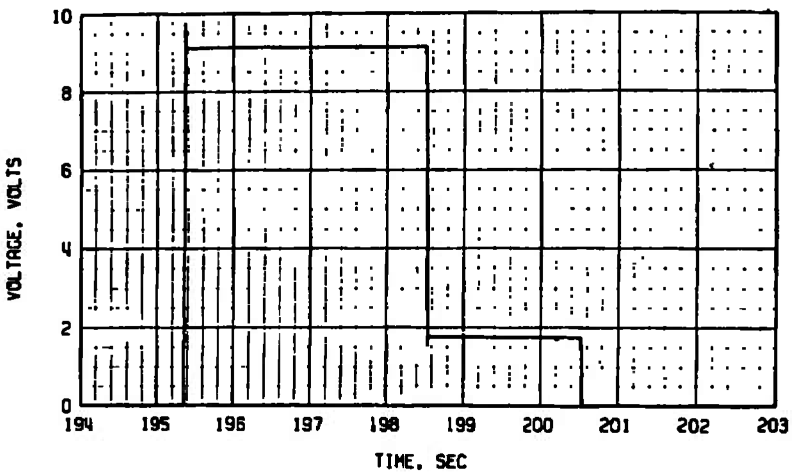


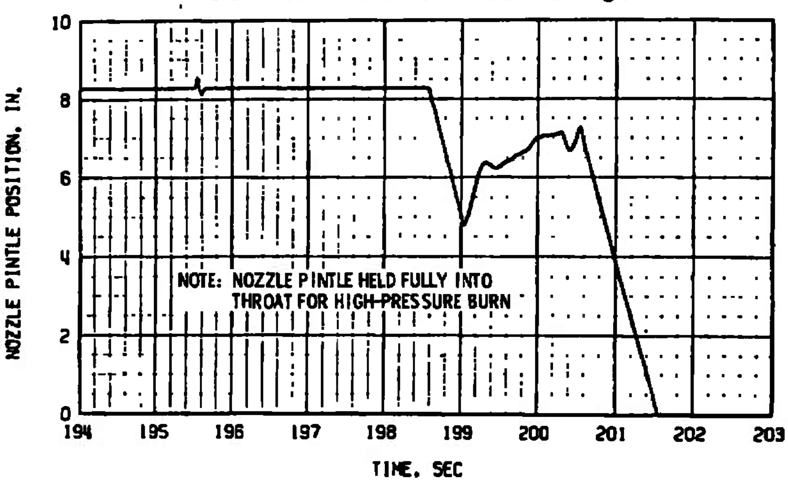
Figure 18. Vacuum axial thrust, chamber pressure, and test cell pressure, fourth firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 19. Nozzle pintle command voltage and position, fourth firing.

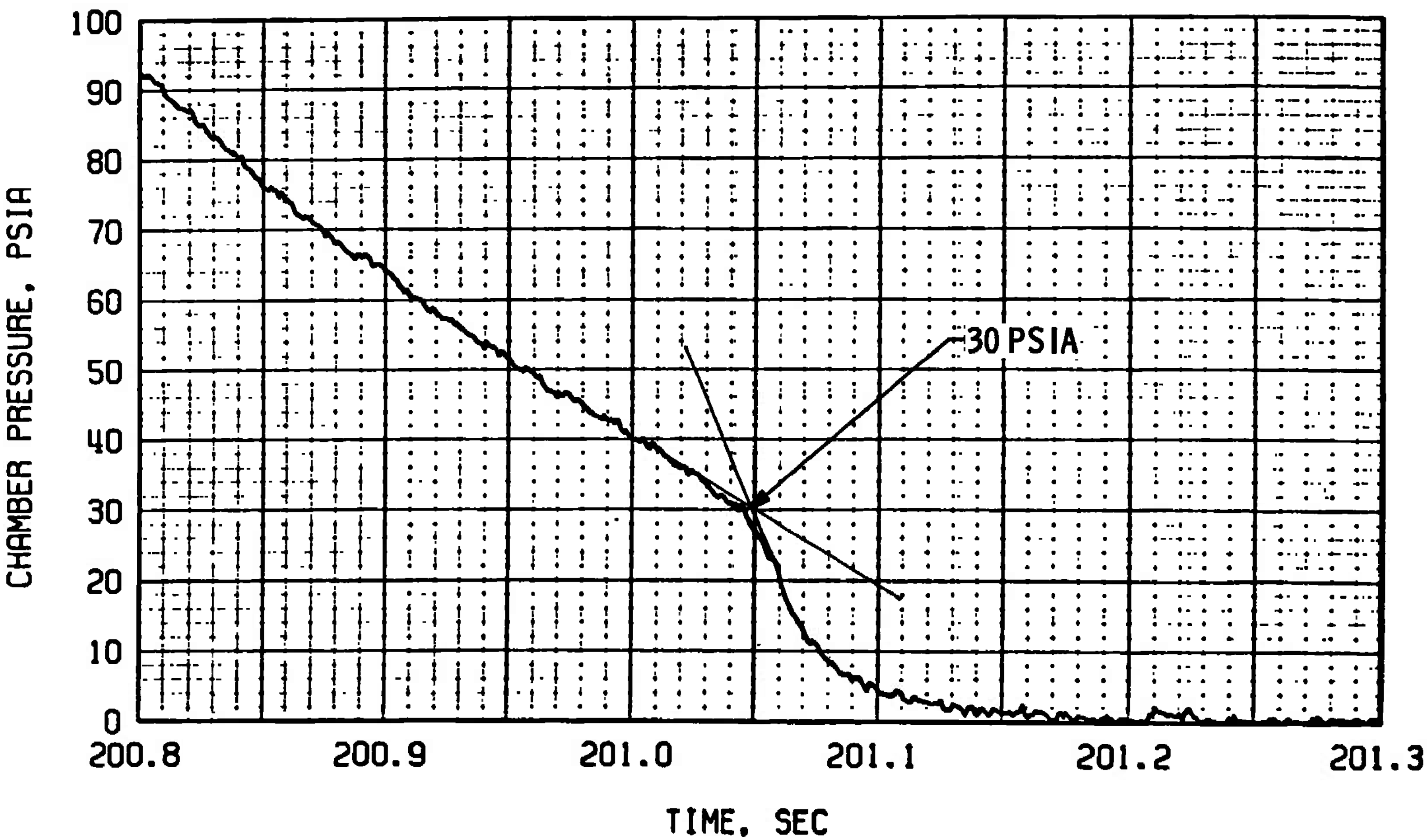


Figure 20. Chamber pressure during extinguishment, fourth firing.

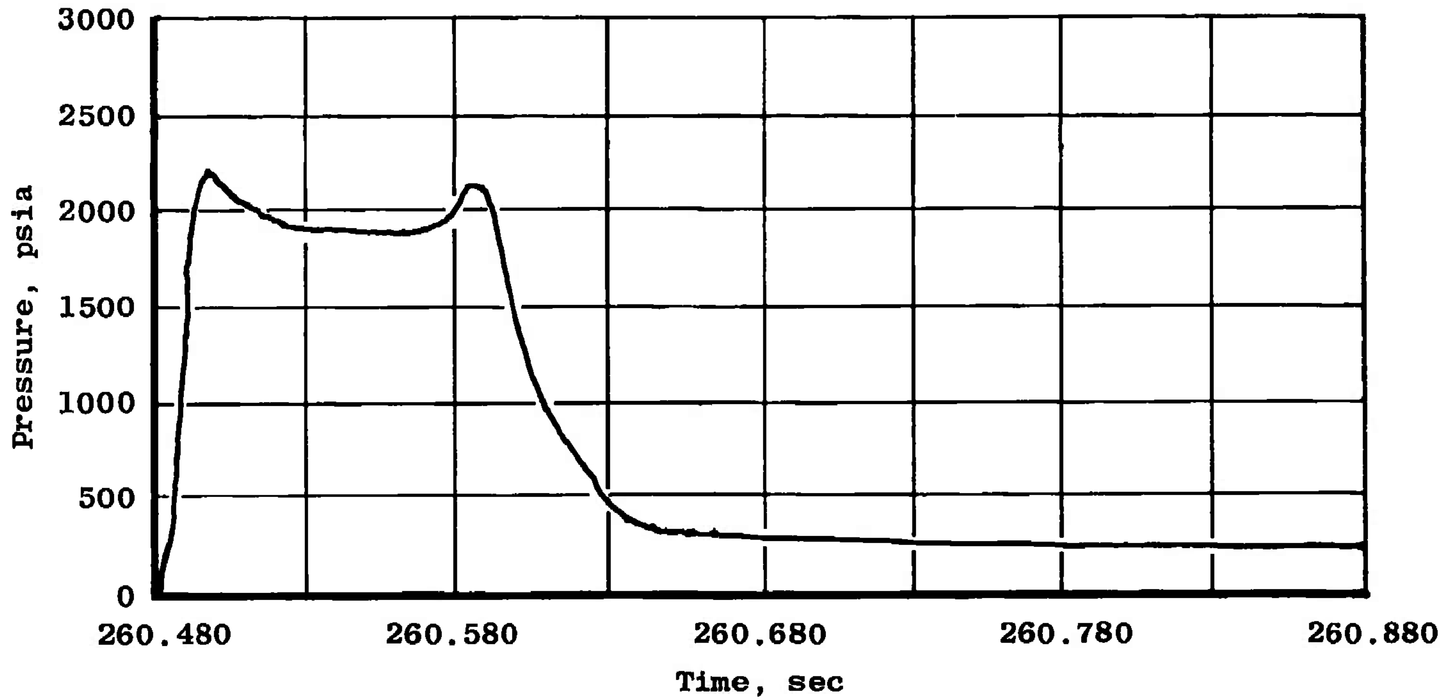


Figure 21. Igniter pressure during ignition transient, fifth firing.

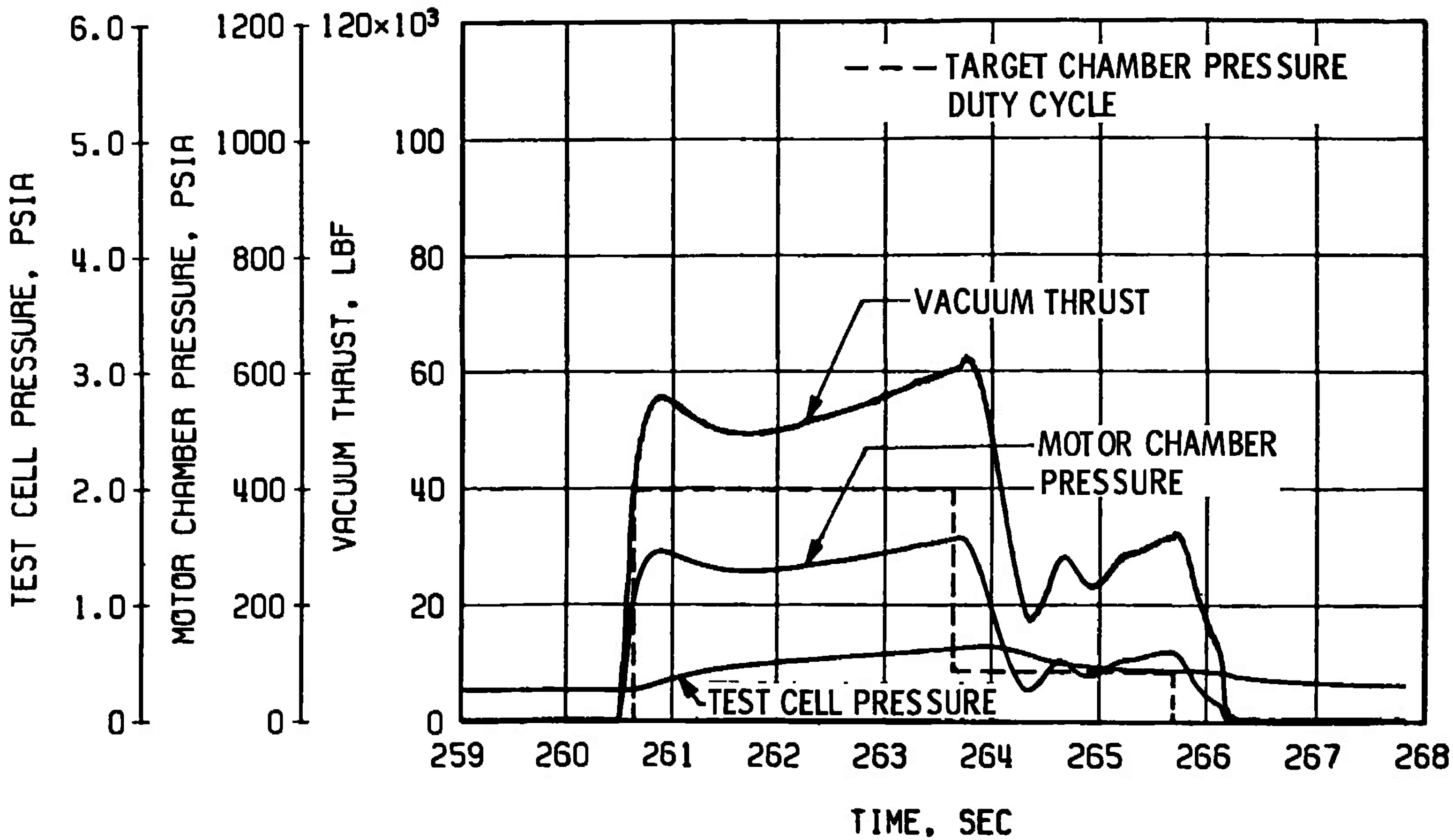
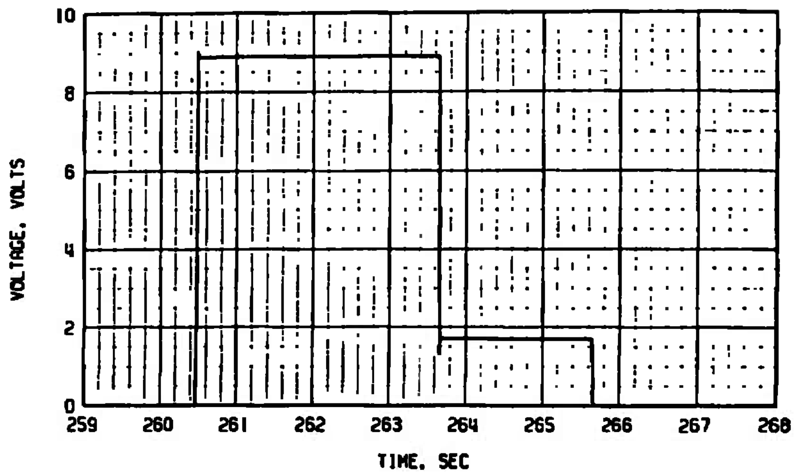
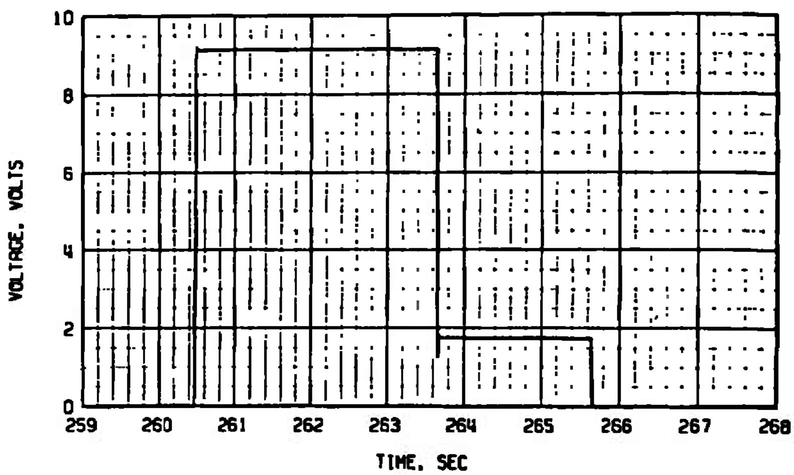


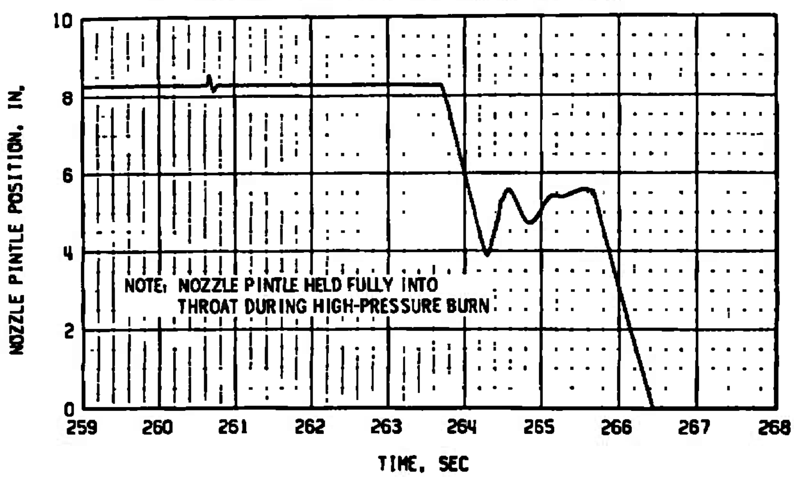
Figure 22. Vacuum axial thrust, chamber pressure, and test cell pressure, fifth firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 23. Nozzle pintle command voltage and position, fifth firing.

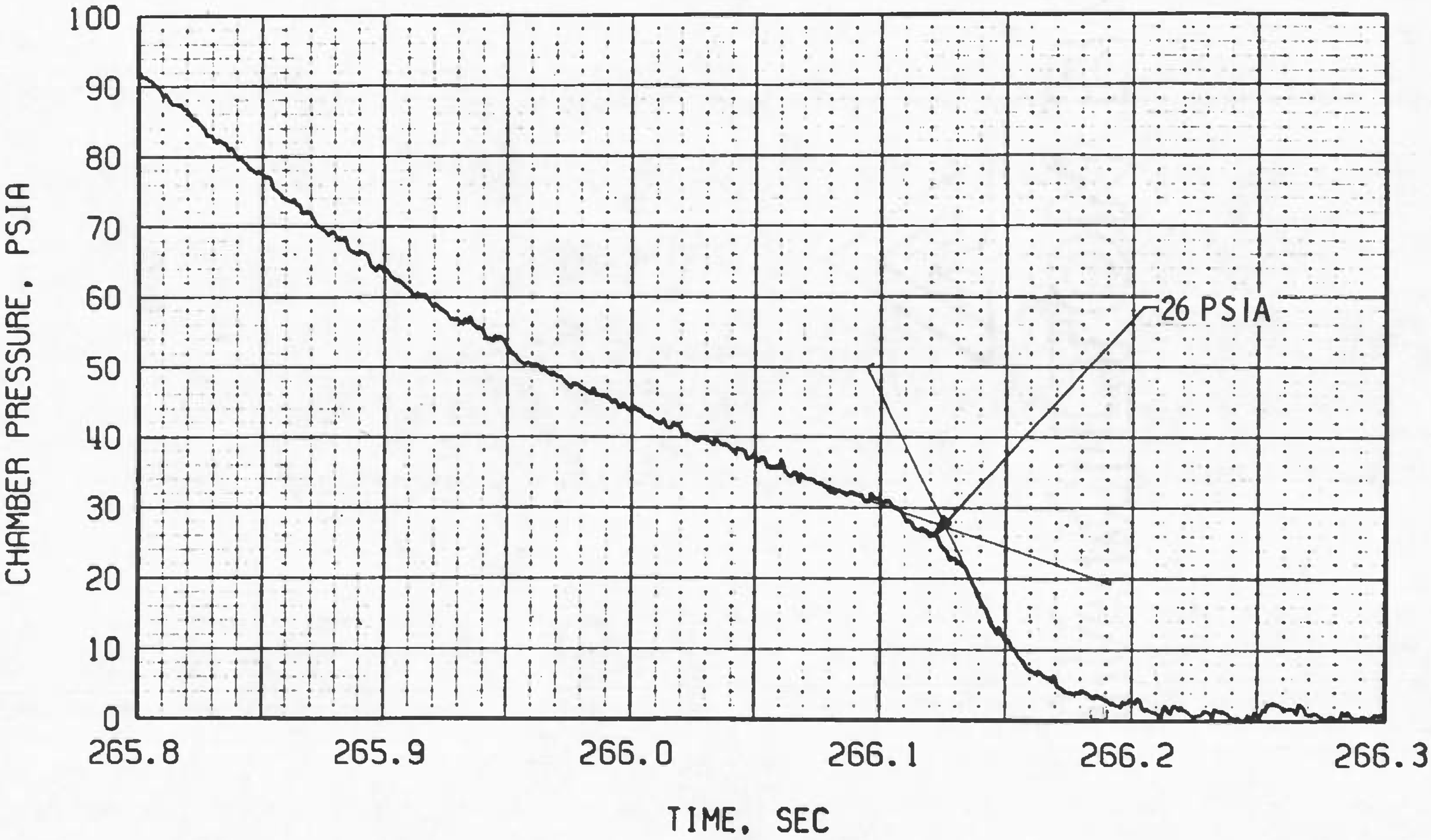
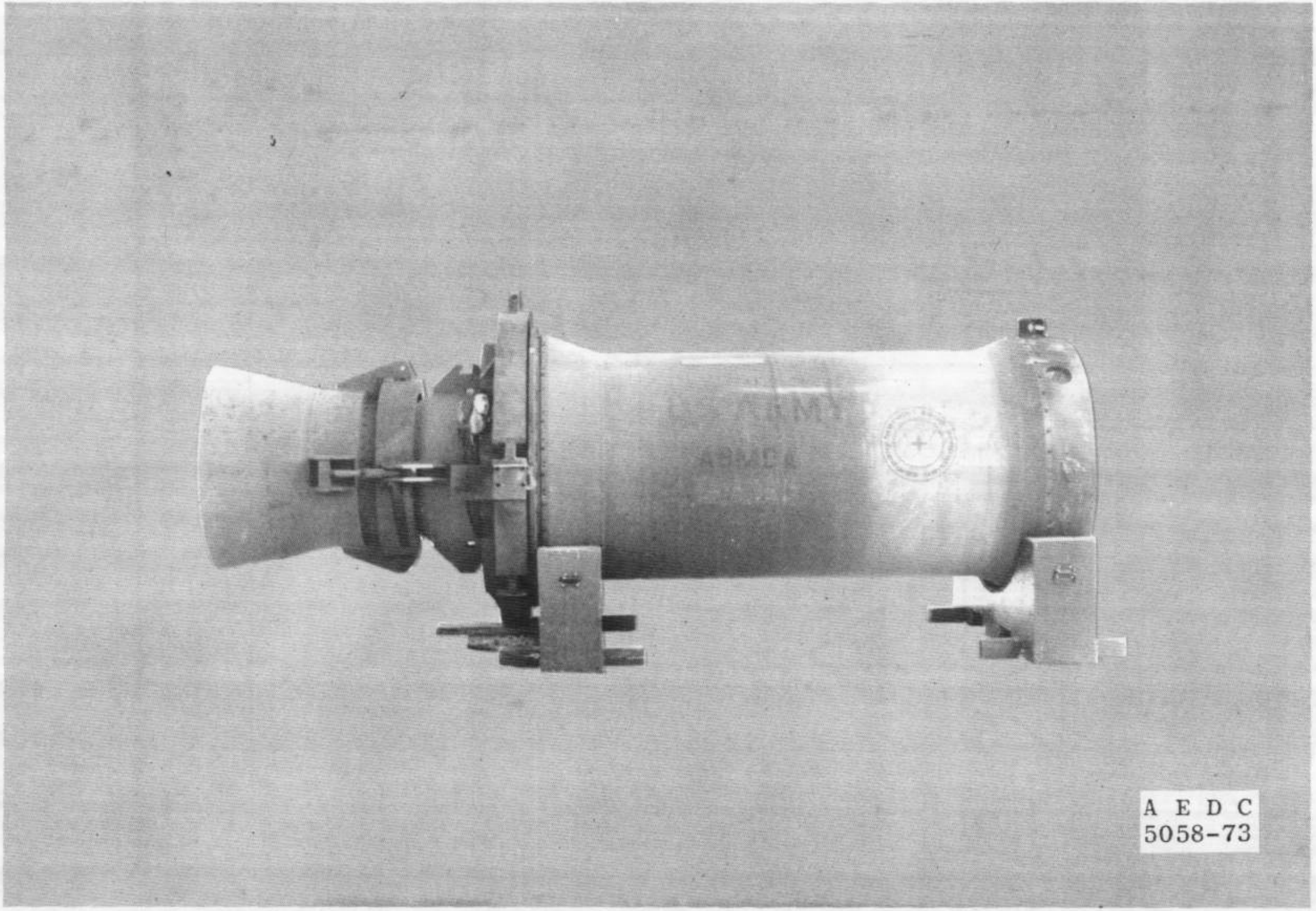
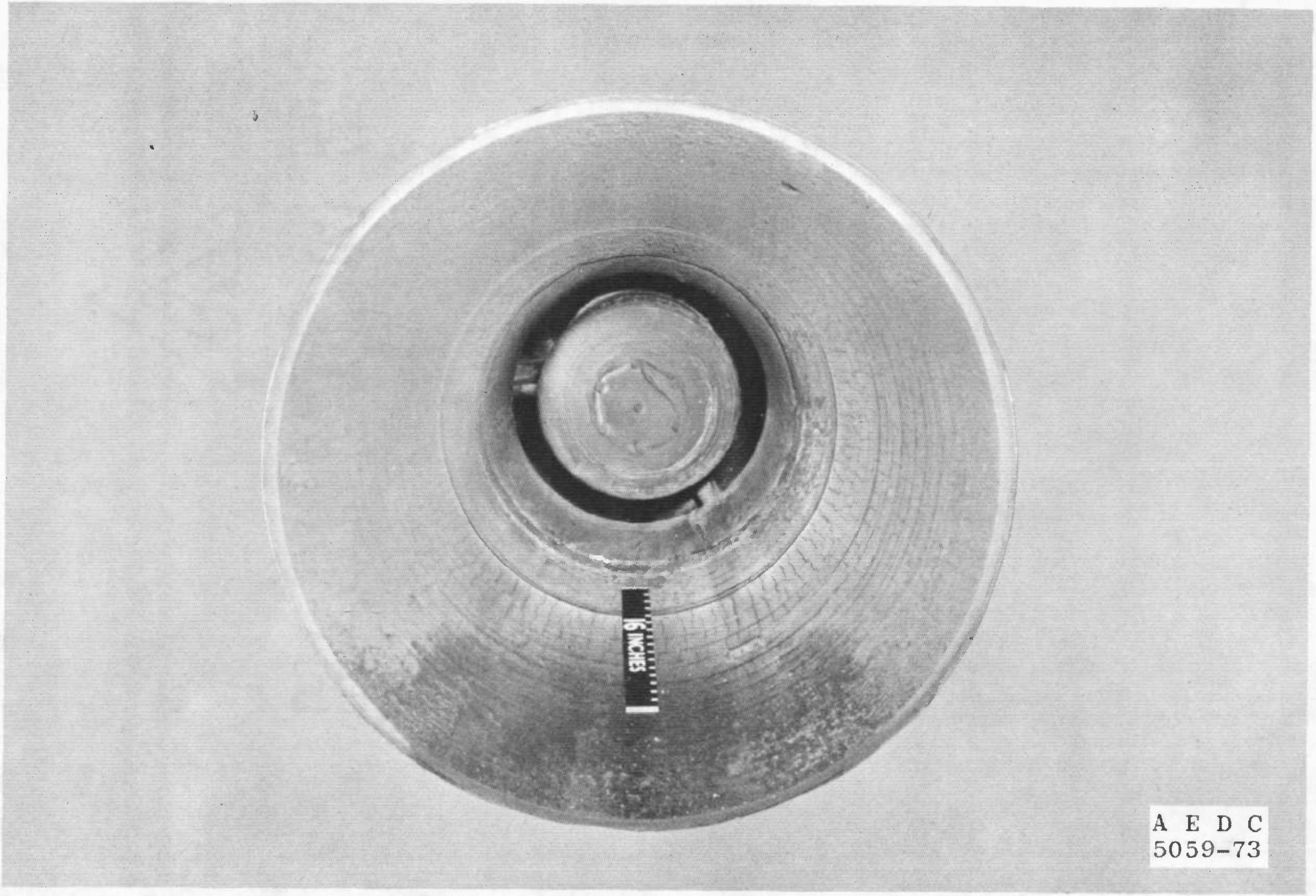


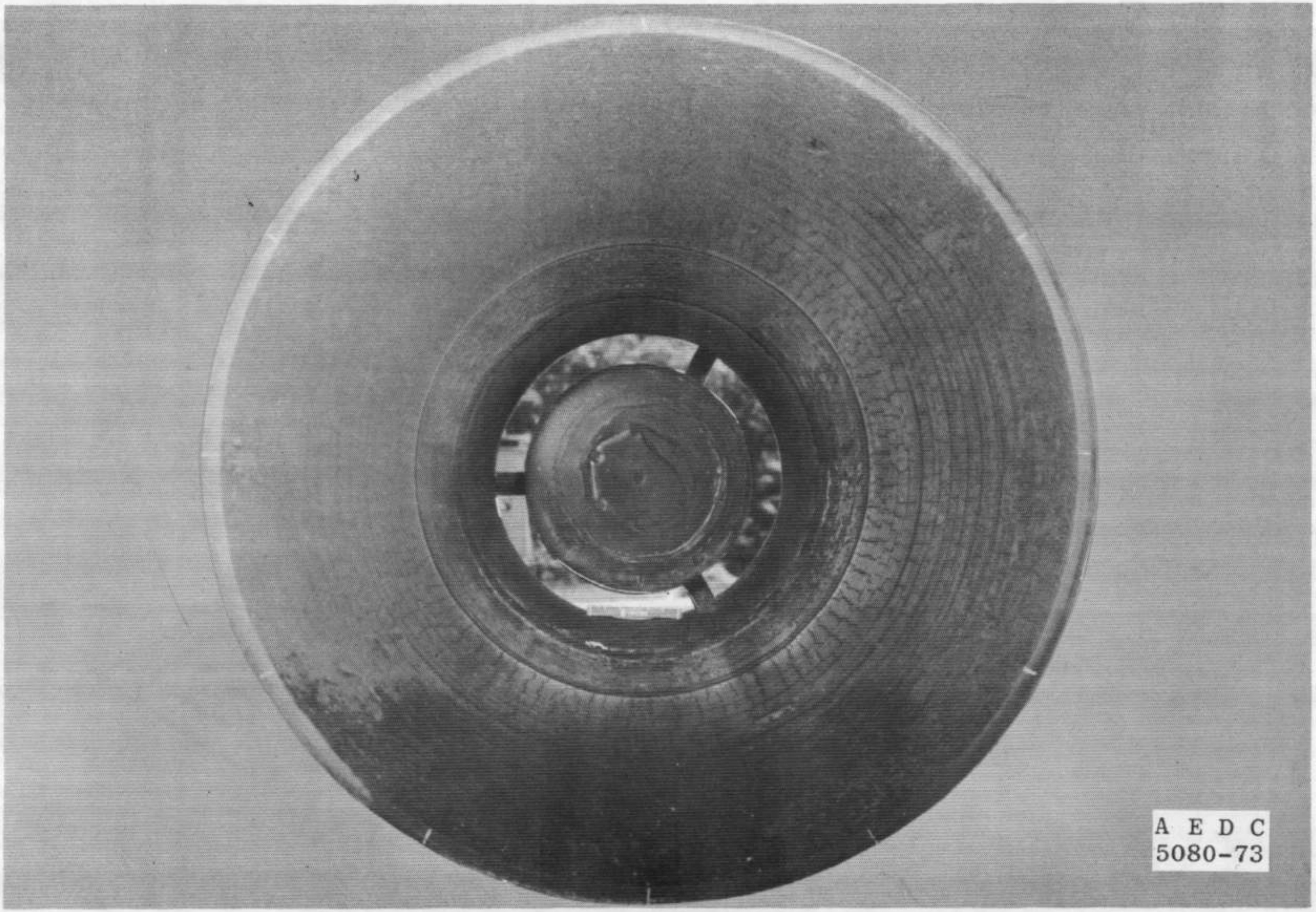
Figure 24. Chamber pressure during extinguishment, fifth firing.



a. Overall view
Figure 25. Test article postfire.

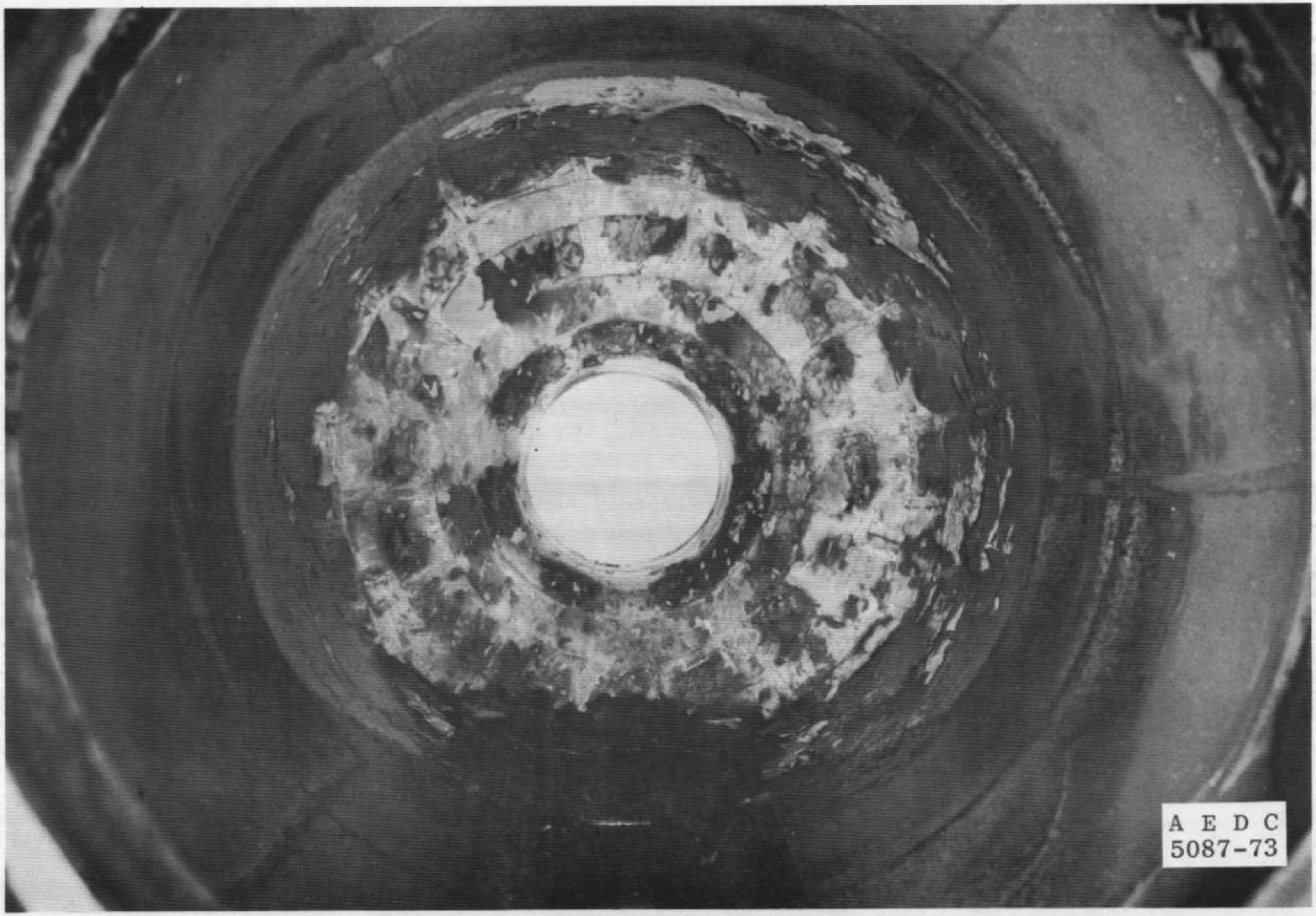


b. Nozzle end view
Figure 25. Concluded.

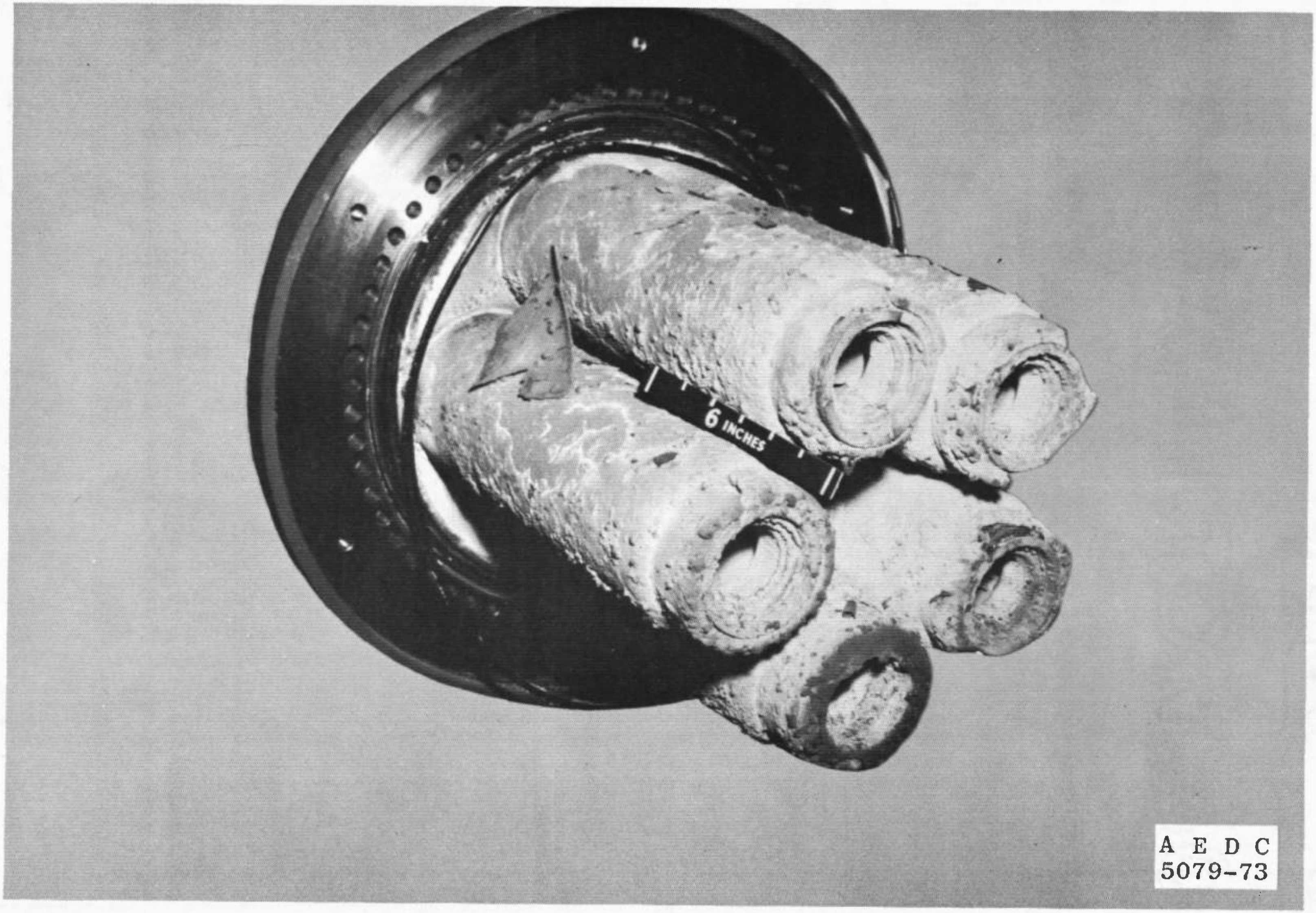


a. Nozzle end view
Figure 26. Posttest disassembly.

b. Overall view of pintle
Figure 26. Continued.



c. Motor chamber
Figure 26. Continued.



d. Igniter plate
Figure 26. Concluded.

Table 1. Instrumentation Summary

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	ACCELERATION	G PEAK		G PEAK				
AIGNY	IGNITER BOSS AXIAL	-200 TO 200	PIEZOELECTRIC	-1K TO 1K		X		
	EVENT-VOLTAGE	V DC						
EFS-1	MAIN MOTOR IGNITION	0 TO 35			X	X	X	
EFS-2	MAIN MOTOR IGNITION	0 TO 35			X		X	
EFS-3	MOTOR IGNITION	0 TO 35			X	X	X	
EFS-4	MOTOR IGNITION	0 TO 35			X		X	
EFS-5	MOTOR IGNITION	0 TO 35			X	X	X	
EFS-6	MOTOR IGNITION	0 TO 35			X		X	
EFS-9	MOTOR IGNITION	0 TO 35			X	X	X	
EFS-10	MOTOR IGNITION	0 TO 35			X	X	X	
	EVENT	V DC						
EEC	EXTINGUISHMENT COMM.	0 TO 28			X		X	
EIA	NOZZLE PINTLE SERVO	- 10 TO 10			X		X	
EILI	INITIAL POS. INTLK	0 TO 28			X		X	
EP	NOZZLE PINTLE COMM.	- 10 TO 10			X		X	
EPCFB	CHAMBER PRES FEEDBK.	0 TO 10			X		X	
EPCP	PRES. COMM. PROGRAM.	- 10 TO 10			X		X	
EPPS	PINTLE PROGRAM START	0 TO 28			X		X	
ERRP-1	NOZ PINTLE ERROR SIG	- 10 TO 10			X		X	
ERRP-2	NOZ PINTLE ERROR SIG	- 10 TO 10			X		X	
ETCPS	TRANSFER TO PRESSURE	0 TO 28			X		X	
	FORCE	LBF		LBF				
FY-1	AXIAL THRUST	-25000 TO 125000	STRAIN GAGE	-500K TO 500K	X**		X	X
FY-2	AXIAL THRUST	-25000 TO 125000	STRAIN GAGE	-500K TO 500K	X		X	
FY-3	AXIAL THRUST	-25000 TO 125000	STRAIN GAGE	-500K TO 500K	X	X		
FY-4	AXIAL THRUST	-25000 TO 125000	STRAIN GAGE	-500K TO 500K		X		
	EVENT-CURRENT	AMPS						
IFS-1	MAIN MOTOR IGNITION	0 TO 10			X		X	
IFS-2	MAIN MOTOR IGNITION	0 TO 10			X		X	
IFS-3	MOTOR IGNITION	0 TO 10			X		X	

Table 1. Concluded

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	EVENT-CURRENT	AMPS						
IFS-4	MOTOR IGNITION	0 TO 10			X		X	
IFS-5	MOTOR IGNITION	0 TO 10			X		X	
IFS-6	MOTOR IGNITION	0 TO 10			X		X	
IFS-9	MOTOR IGNITION	0 TO 20			X		X	
IFS-10	MOTOR IGNITION	0 TO 20			X		X	
	POSITION	INCHES		INCHES				
LP	NOZZLE PINTLE	0 TO 10	POTENTIOMETRIC	0 TO 10	X**	X	X	X
	PRESSURE	PSIA		PSIA				
PA-1	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X		X	
PA-2	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X			
PA-3	TEST CELL	0 TO 5	STRAIN GAGE	0 TO 5	X			X
PA-5	TEST CELL	0 TO 15	STRAIN GAGE	0 TO 15		X		
PAS-1	TEST CELL (SPECIAL)	0 TO 50	STRAIN GAGE	0 TO 50	X		X	
PC-1	MOTOR CHAMBER	0 TO 500	STRAIN GAGE	0 TO 500	X**	X	X	
PC-2	MOTOR CHAMBER	0 TO 500	STRAIN GAGE	0 TO 500	X	X	X	X
PC-3	MOTOR CHAMBER	0 TO 500	STRAIN GAGE	0 TO 500	X	X	X	
PI-1	MOTOR IGNITER #1	0 TO 3000	STRAIN GAGE	0 TO 3500	X		X	
PI-2	MOTOR IGNITER #2	0 TO 3000	STRAIN GAGE	0 TO 3500	X		X	
PI-3	MOTOR IGNITER #3	0 TO 3000	STRAIN GAGE	0 TO 3500	X		X	
PI-4	MOTOR IGNITER #4	0 TO 3000	STRAIN GAGE	0 TO 3500	X		X	
PI-5	MOTOR IGNITER #5	0 TO 3000	STRAIN GAGE	0 TO 3500	X		X	
PPC	PINTLE CAVITY	0 TO 100	STRAIN GAGE	0 TO 100	X			X
PPEX	PINTLE HYDR. EXTEND	0 TO 5000	STRAIN GAGE	0 TO 5000	X		X	
PPRE	PINTLE HYDR. RETRACT	0 TO 5000	STRAIN GAGE	0 TO 5000	X		X	
PPSY	PINTLE HYDR. SUPPLY	0 TO 5000	STRAIN GAGE	0 TO 5000	X		X	X
	TEMPERATURE	DEG. F		DEG. F				
TA-1	AMBIENT TEST CELL	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TA-2	AMBIENT TEST CELL	0 TO 2500	C/A, TYPE K	-300 TO 2500	X			
TA-5	AMBIENT TEST CELL	0 TO 1000	C/A, TYPE K	-300 TO 2500	X			
TP-1	PROPELLANT GRAIN	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TP-2	PROPELLANT GRAIN	0 TO 350	C/A, TYPE K	-300 TO 2500	X			

*BASIC SAMPLE RATE 200 SAMPLES PER SECOND
**DATA SUPERCOMMUTATED TO 1000 SAMPLES PER SECOND

Table 2. Instrumentation Uncertainties

INSTRUMENTATION MEASUREMENT	UNCERTAINTY, PERCENT, FULL SCALE
Pressure Transducer	±0.44
Chromel®-Alumel® Thermocouple	±0.47
Axial-Force Load Cell	±0.4

Table 3. Motor Temperature

Date	Temperature, °F		Location of Motor	Relative Humidity, percent		Remarks
	High	Low		High	Low	
5/7/73	76	73	X-ray Lab	50	35	Motor received at X-ray Lab
5/8/73	83	75		59	39	
5/9/73	81	75		44	42	
5/10/73	76	69		42	42	
5/11/73	71	68		44	40	
5/12/73	70	69		47	45	
5/13/73	69	66		45	43	
5/14/73	72	67		43	34	
5/15/73	70	66		38	31	
5/16/73	74	66		36	26	
5/17/73	72	69		39	25	
5/18/73	70	69		29	28	
5/18/73	79	78	Rocket Preparation Area	40	30	Motor moved to Rocket Preparation
5/19/73	79	78		62	40	Area, exposed to 69°F for 50 min
5/20/73	79	78		62	55	
5/21/73	80	77		60	44	
5/22/73	79	77		66	49	
5/23/73	79	78		70	64	
5/24/73	79	78		69	62	
5/25/73	79	77		67	56	
5/26/73	78	74		68	56	
5/27/73	78	76		71	66	
5/28/73	75	74		65	61	
5/29/73	76	74		63	59	
5/30/73	75	74		64	59	
5/31/73	75	74		63	53	
6/1/73	75	74		67	51	
6/2/73	76	74		70	54	
6/3/73	76	74		70	59	
6/4/73	74	72		70	60	
6/5/73	75	74		70	60	
6/6/73	75	74		70	59	
6/7/73	75	74		70	58	
6/8/73	75	72		70	64	
6/9/73	74	72		69	64	
6/10/73	74	72		69	64	
6/11/73	74	74		69	66	
6/12/73	75	72		70	60	

Table 3. Concluded

Date	Temperature, °F		Location of Motor	Relative Humidity, percent		Remarks
	High	Low		High	Low	
6/13/73	73	73	Rocket Preparation Area	60	59	
6/14/73	73	72		59	54	
6/15/73	73	72				
6/16/73	72	70				
6/17/73	71	70		64	59	
6/18/73	72	70				
6/19/73						
6/19/73	71	71				Motor moved to test cell, exposed to 81°F for 1 hr
6/20/73	71	67		66	59	
6/21/73	71	69		62	60	
6/22/73	74	70		62	60	
6/23/73	74	72				
6/24/73	74	70				
6/25/73	73	69	Test Cell			Motor fired at 2205 hours

Table 4. Nozzle Measurements

Location, deg	Prefire Throat Annular Gap*, in.	Prefire Exit, in.	Postfire Exit, in.
0	1.963	39.889	39.908
30		39.885	39.872
60		39.912	39.839
90	2.060	39.984	39.868
120		39.908	39.880
150		39.917	39.901
180	2.000		
270	1.917		
Average, in.		39.916	39.878
Area, sq in.		1251.36	1248.98
Percent Change in Area			-0.2

*Nozzle pintle in fully extended position

Table 5. Summary of Motor Performance

General Information	
Motor Designation	CSRM-4
Date Cast	3-23-73
Date Fired	6-25-73
Gross Motor Weight, lbm	13,387
Manufacturer's Stated Propellant Weight, lbm	5,950
Prefire Nozzle Exit Area, sq in.	1251.364
Prefire Motor Temperature, deg F.	69
Altitude	
First Firing	
at Ignition, ft	88,000
Average until Extinguishment, ft	72,000
Second Firing	
at Ignition, ft	89,000
Average until Extinguishment, ft	71,000
Third Firing	
at Ignition, ft	89,000
Average until Extinguishment, ft	76,000
Fourth Firing	
at Ignition, ft	89,000
Average until Extinguishment, ft	78,000
Fifth Firing	
at Ignition, ft	89,000
Average until Extinguishment, ft	76,000
Time	
First Firing	
Ignition, sec	T-0
Transfer to Pressure Mode, sec	T+0.160
Extinguishment Command, sec	T+5.175
Extinguishment, sec	T+5.78
Second Firing	
Ignition, sec	T+65.145
Transfer to Pressure Mode, sec	T+65.275
Extinguishment Command, sec	T+70.285
Extinguishment, sec	T+70.86
Third Firing	
Ignition, sec	T+130.245
Transfer to Pressure Mode, sec	T+130.385
Extinguishment Command, sec	T+135.425
Extinguishment, sec	T+135.85

Table 5. Continued

<u>Time</u> (Cont'd)	
Fourth Firing	
Ignition, sec	T+195.360
Transfer to Pressure Mode, sec	T+195.505
Extinguishment Command, sec	T+200.520
Extinguishment, sec	T+201.05
Fifth Firing	
Ignition, sec	T+260.480
Transfer to Pressure Mode, sec	T+260.625
Extinguishment Command, sec	T+265.645
Extinguishment, sec	T+266.12
<u>Chamber Pressure</u>	
First Firing	
High-Pressure Step	
Average, psia	335
Low-Pressure Step	
Average, psia	147
Extinguishment, psia	36
Second Firing	
High-Pressure Step	
Average, psia	402
Low-Pressure Step	
Average, psia	153
Extinguishment, psia	26
Third Firing	
High-Pressure Step	
Average, psia	274
Low-Pressure Step	
Average, psia	136
Extinguishment, psia	32
Fourth Firing	
High-Pressure Step	
Average, psia	224
Low-Pressure Step	
Average, psia	127
Extinguishment, psia	30
Fifth Firing	
High-Pressure Step	
Average, psia	277
Low-Pressure Step	
Average, psia	127
Extinguishment, psia	26

Table 5. Concluded

Axial Force

First Firing	
High-Pressure Step	
Average Measured, lbf	71,100
Average Vacuum, lbf	71,800
Low-Pressure Step	
Average Measured, lbf	38,300
Average Vacuum, lbf	39,000
Second Firing	
High-Pressure Step	
Average Measured, lbf	79,700
Average Vacuum, lbf	80,500
Low-Pressure Step	
Average Measured, lbf	36,900
Average Vacuum, lbf	37,700
Third Firing	
High-Pressure Step	
Average Measured, lbf	53,400
Average Vacuum, lbf	54,000
Low-Pressure Step	
Average Measured, lbf	30,200
Average Vacuum, lbf	30,800
Fourth Firing	
High-Pressure Step	
Average Measured, lbf	42,000
Average Vacuum, lbf	42,600
Low-Pressure Step	
Average Measured, lbf	28,000
Average Vacuum, lbf	28,600
Fifth Firing	
High-Pressure Step	
Average Measured, lbf	52,500
Average Vacuum, lbf	53,100
Low-Pressure Step	
Average Measured, lbf	31,800
Average Vacuum, lbf	32,500

APPENDIX A
CALIBRATION

Axial-Force System

The axial-force load cell was physically calibrated in the calibration laboratory before installation in the test cell force-measuring system by direct application of loads traceable to the National Bureau of Standards (NBS). The instrumentation recording systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions using a resistance shunting method to simulate load cell output.

Pressure Transducers

The pressure transducers were physically calibrated in the AEDC calibration laboratory before installation by direct application of pressure loads traceable to the NBS. The instrumentation recording systems were calibrated at ambient conditions.and, subsequently, at pressure altitude conditions using a resistance shunting method to simulate pressure transducer output.

Temperatures

The thermocouples were fabricated from standard thermocouple wire, the electromotive force output of which is traceable to the NBS through the wire manufacturer. The thermocouples were connected directly to a 150°F reference temperature junction, and the NBS standard temperature/voltage relationships were used for conversions to engineering units. The temperature instrumentation systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions by the voltage substitution method which simulated a known input signal.

Position Potentiometer

Nozzle pintle position potentiometer feedback voltage as a function of measured pintle position was determined at AEDC. This relationship was not linear, and intermediate points between the fully retracted and the fully extended positions were determined.

APPENDIX B
METHODS OF CALCULATION

1. PALT = Average test cell pressure, psia

   PALT = (PA-1 + PA-2)/2

2. PCA = Average chamber pressure, psia

   PCA = (PC-1 + PC-2)/2

3. FA = Average axial force, lbf

   FA = (FY-1 + FY-2)/2

4. FAVAC = Vacuum axial thrust, lbf

   FAVAC = FA + PALT (AE)

   where AE = Prefire nozzle exit area measured at AEDC

5. FPE = Pintle ejection force, lbf

   FPE = 26.97 (PPRE) -28.87 (PPEX)

6. RFPPC = Pintle ejection force to average chamber pressure ratio, lbf/psia

   RFPPC = FPE/PCA

7. RFYPC = Vacuum axial thrust to average chamber pressure ratio, lbf/psia

   RFYPC = FAVAC/PCA